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DISTRIBUTION AND ABUNDANCE OF EGGS OF THE PACIFIC SARDINE, 1952-1956

By Elbert H. Ahlstrom

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ABSTRACT

Distribution and abundance of eggs of the Pacific sardine (*Sardinops caerulea*) are given for the years 1952 through 1956. During this period a major change occurred in distribution of sardine spawning. In 1952 and 1953 sardine spawning was mostly confined to waters off central Baja California, but in 1954 sardine spawning spread northward to waters off southern California, and this distribution continued through 1955 and 1956. Estimates of total eggs spawned during these years ranged from 136×10^{12} to 436×10^{12} eggs.

During the major spawning period (January–July off southern California and northern Baja California; January–June off central Baja California) sardine eggs were found at temperatures between 11.0° and 21.2° C. (mean, 15.2° C.); during the later spawning period (July–December off central Baja California) at temperatures between 11.3° and 27.4° C. (mean, 18.1° C.). The average temperature at which sardine eggs were found increased in a fairly uniform fashion from north to south within the spawning range during the major spawning period.

Temperatures at which sardine eggs were obtained off southern California were slightly lower in 1951–56 than in 1940 and markedly lower than in 1941.

DISTRIBUTION AND ABUNDANCE OF EGGS OF THE PACIFIC SARDINE 1952–1956

By ELBERT H. AHLSTROM, *Fishery Research Biologist*
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In a previous report (Ahlstrom 1954b) I discussed the distribution and abundance of egg and larval populations of the Pacific sardine (*Sardinops caerulea*) in 1950 and 1951. This report is a continuation of the record on distribution and abundance of sardine eggs for the years 1952 through 1956.

During the period covered by the present report, a major change occurred in the distribution of sardine spawning. In 1952 and 1953, spawning was mostly confined to waters off central Baja California; in 1954 through 1956, heavy and widespread sardine spawning occurred off southern California and adjacent Baja California as well as off central Baja California. This shift in a part of the spawning population was associated with a marked change in the availability of sardines to the California commercial fishery, as will be discussed later.

Investigation of the egg and larval populations of the sardine is part of a large-scale cooperative research program, the California Cooperative Oceanic Fisheries Investigations, which is sponsored by the California Marine Research Committee and carried out cooperatively by the Scripps Institution of Oceanography of the University of California, the Bureau of Marine Fisheries of the California Department of Fish and Game, the La Jolla Biological Laboratory of the U.S. Bureau of Commercial Fisheries, the Hopkins Marine Station of Stanford University, and the California Academy of Sciences. The oceanographic-biological survey program is the primary responsibility of the Scripps Institution of Oceanography and the La Jolla Biological Laboratory; the California Department of Fish and Game has participated in some cruises.

NOTE.—Approved for publication, Sept. 2, 1958. Fishery Bulletin 165.

The collections were made on the following research vessels: *E. W. Scripps*, *Crest*, *Horizon*, *Paolina T.*, *Spencer F. Baird*, *Stranger*, and *Orca*, operated by the Scripps Institution of Oceanography; the *N. B. Scofield* and *Yellowfin*, operated by the California Department of Fish and Game; and the *Black Douglas*, operated by the La Jolla Biological Laboratory. I take deep pleasure in acknowledging the cooperation given by the crews of the vessels and scientific personnel of these organizations in the collection of data at sea. Most of the personnel of the La Jolla Biological Laboratory have devoted their full time to this investigation. The distribution charts were prepared by James R. Thrailkill, the graphs by Andrew M. Vrooman. Sardine egg drawings were made by George M. Mattson.

SARDINE SPAWNING SURVEYS, 1952–56

A large-scale oceanographic-biological survey program was initiated in 1949; the distribution and density of sampling stations during the first 3 years of the program were discussed by Ahlstrom (1954b). The location and number of stations occupied during 1952 through 1956 are summarized in table 1 and illustrated in figure 1. With but few exceptions, cruises were spaced at monthly intervals. During the 5 years under consideration, there were 48 regular survey cruises, 9 cruises with partial coverage, and only 3 months with no sampling at all. On each regular survey cruise there was systematic sampling of waters off California and Baja California. A minimum sampling on a regular survey cruise was obtained in the area between Point Conception, southern California, and Point San Juanico, Baja California (station lines 80–137); a more extensive coverage was obtained on many cruises. Except for August 1956, there were survey cruises at monthly

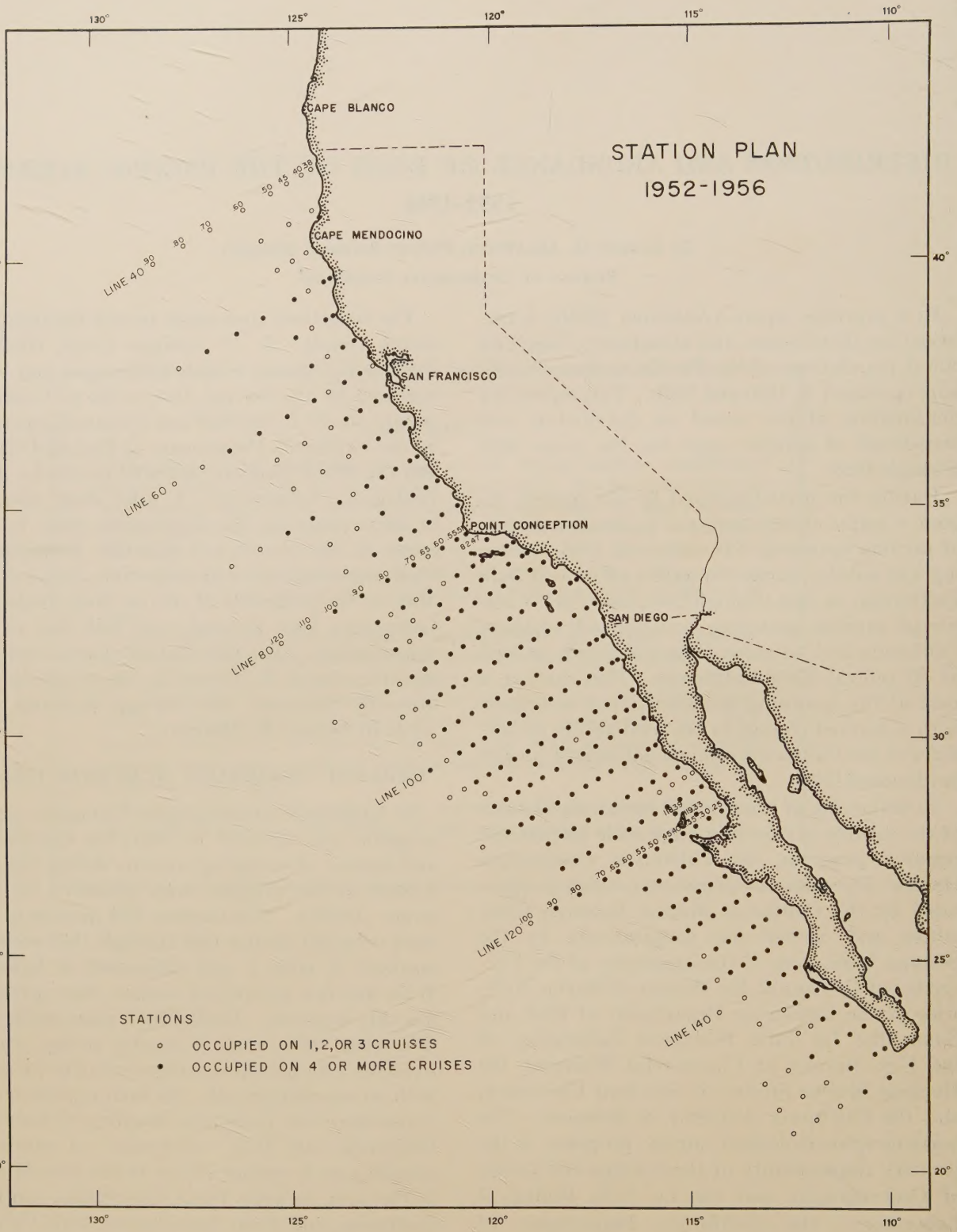

FIGURE 1.—Location of stations occupied during survey cruises made in 1952–56.

intervals during the first 8 months of each year. During the last 4 months, coverage was least extensive during September and November.

Sampling in all years was most intensive during the period of heavy sardine spawning, March through July. After July, it was most thorough in Sebastian Viscaino Bay and in coastal waters off central Baja California, where some sardine spawning takes place throughout the latter part of the year.

TABLE 1.—*Area covered and number of stations occupied on cruises of the California Cooperative Oceanic Fisheries Investigations, 1952–56*

	1952		1953		1954		1955		1956	
	Area covered (lines)	Number of stations occupied	Area covered (lines)	Number of stations occupied	Area covered (lines)	Number of stations occupied	Area covered (lines)	Number of stations occupied	Area covered (lines)	Number of stations occupied
January	80–137	94	80–150	98	77–150	134	80–157	112	80–157	111
February	80–150	109	80–137	95	77–137	116	80–157	117	80–157	131
March	80–137	154	80–137	175	77–137	153	80–157	142	80–137	140
April	60–137	158	60–137	208	60–137	196	80–137	152	60–157	178
May	60–137	186	60–137	222	60–137	205	63–137	184	40–137	239
June	50–137	222	60–137	204	50–137	209	60–137	189	40–137	212
July	40–137	179	60–137	121	60–137	118	63–137	196	60–137	202
August	60–137	99	60–137	118	60–137	122	Norpac	198	110–137	36
September	60–137	94	83–87, 113–120	40			83–90	169	110–137	36
October	60–137	88	83–137	69	77–137	106	60–137	108	80–97	42
November	60–137	91	83–87	19			83–90	84	80–97	40
December			83–137	82	80–157	115	80–137	106	80–97	42
Total	40–150	1,474	60–150	1,451	50–157	1,474	60–157	1,757	40–157	1,409

Although the total number of plankton hauls taken per year during 1952–56 was fairly similar, the temporal and areal distributions of stations were modified year by year to intensify the sampling within spawning areas at the expense of the coverage in other areas.

Detailed records were kept of each plankton haul taken during 1952 through 1956 (Staff of the South Pacific Fishery Investigations, 1953, 1954, 1955, 1956; Thrailkill 1957). Included in the record for each haul were position, date and time of occupancy, volume of water strained, depth of stratum through which the net was hauled, and volume of plankton obtained.

ESTIMATING ABUNDANCE OF SARDINE EGGS

Methods of estimating abundance of pelagic fish eggs were described by Sette and Ahlstrom (1948) and Ahlstrom (1954b). An estimate of the number of sardine eggs spawned during each cruise (C) is obtained from

$$C=\sum_i (c_i w_i t_i)$$

in which c_i = an estimate of the number of sardine eggs spawned per day in a standard area representing 10 square meters of sea surface at the i-th station, derived by dividing the total number of sardine eggs in a standard haul by the total number of age categories represented—this is equivalent to c_{ig}, as defined in Ahlstrom (1954b); w_i = the weighting factor for space, in standard areas, that is proportional to the area of the polygon at the i-th station bounded by constructing perpendicular bisectors to lines drawn from that station to each of the adjacent stations; and t_i = the time weighting given to the i-th station, equal to one-half the time elapsed since the preceding occupancy plus one-half the time elapsed prior to the succeeding occupancy.[1]

The estimated number of eggs spawned within the survey area during the year is obtained by summing C for all cruises.

Sardine eggs require from 1 to 5 days (usually 2 to 4) to develop from spawning to hatching, depending upon the temperature of the water during incubation. Sardine spawning takes place mostly during a 4-hour period, 8 p.m. to midnight (Ahlstrom 1943). Because successive spawning periods are separated by about 20 hours, eggs of the current night's spawning are sharply separated in stage of development from those spawned on the preceding night or nights. Eggs obtained from two fairly typical samples are illustrated in figure 2. Each contained eggs spawned on three consecutive nights. The tem-

[1] The time weighting given to the i-th station approximated 30 days. When coverage of a station was not obtained on successive months, an arbitrary time weighting of 30 days was allowed.

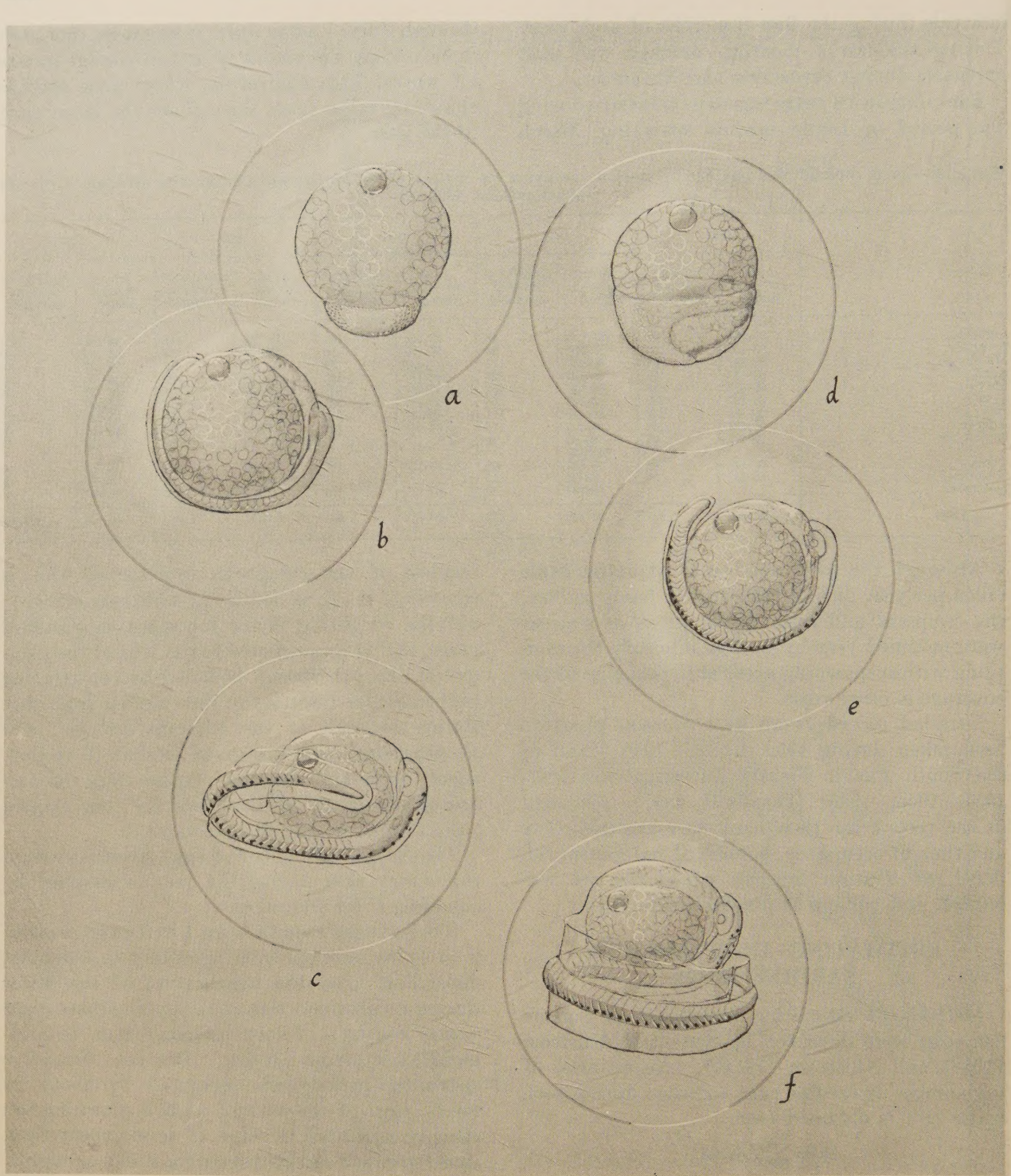

FIGURE 2.—Sardine eggs of different stages of development: a–c, the three stages of development present in a sample collected at 6 a.m. (water temperature 15.5° C.) ; d–f, the three stages of development present in a sample collected at 2 p.m. (water temperature 15.5° C.). The approximate age of each stage (time from spawning) is as follows: a, 8 hours; b, 32 hours; c, 56 hours; d, 16 hours; e, 40 hours; and f, 64 hours.

perature in each instance was similar (15.5° C.), but the times of collection were different—6 a.m. for the group of eggs on the left, 2 p.m. for the group on the right.

In the previous report (Ahlstrom 1954b, table 7), three estimates of the number of sardine eggs were given for 1950 and 1951, based on three different methods of determining c_i, the average number of eggs spawned per day. One method made use of the relation between water temperature and the rate of development of sardine eggs for estimating the number of days' spawning represented in a sample; a second method made use of "aged" eggs, but limited acceptable observations to complete age categories; the third made use of all age categories, except newly spawned eggs collected between 8 p.m. and midnight.

As noted in the formulation above, the third method is employed in this report. It is by far the simplest of the three methods of determining the average number of eggs spawned per day, it is more precise for individual stations than the method employing the relation between water temperature and rate of development, and it has fewer limitations than estimates based on complete age categories (see Ahlstrom 1954b: 99).

Estimates of abundance, making use of all age categories except newly spawned eggs from hauls made between 8 p.m. and midnight in determinations of per day spawning, are slightly lower, however, than estimates derived from the other methods of determining c_i. Obviously, this is because the oldest age category, in some instances, has been reduced by the hatching of some of the eggs. In 1950, for example, estimates based on all age categories were 95.2 percent as high as those based on complete age categories; in 1951 they were 97.8 percent as high, and in 1952, 98.5 percent as high.

The basic data on sardine eggs have been given in the following reports: For 1952, in Ahlstrom (1954a); 1953, in Ahlstrom and Kramer (1955); 1954, in Ahlstrom and Kramer (1956); 1955, in Ahlstrom and Kramer (1957); and 1956, in Ahlstrom (1958). In these reports, sardine eggs are enumerated by age for each collection.

DISTRIBUTION AND ABUNDANCE OF SARDINE EGGS IN 1952

The distribution of sardine eggs in 1952 is illustrated in figure 3. This chart shows relative abundance of eggs; the concentration at each station is the cumulative standard haul total for the year.

The estimated abundance of sardine eggs in 1952 is summarized by month and station line in table 2. This table is comparable to tables 8 and 9 in the previous report (Ahlstrom 1954b). Subtotals are given for six areas, delimited as follows:

1. Area north of Point Conception: northern and central California, station lines 40 to 77.
2. Southern California area: from Point Conception to San Diego, station lines 80 to 93.
3. Northern Baja California area: from the International Border to Point San Quintin, station lines 97–107.
4. Upper central Baja California area: from Point Baja to Point San Eugenio, station lines 110–120.
5. Lower central Baja California area: from off Turtle Bay to Point San Juanico, station lines 123–137.
6. Southern Baja California area: from Cape San Lazaro to Cape San Lucas, station lines 140–157.

In 1952, there were 11 monthly cruises (none in December), and in March, a second survey of the area off central Baja California. The estimate of the number of sardine eggs spawned in 1952 is the lowest for the 7-year period, 1950–56.

Two major sardine spawning centers were pointed out by Ahlstrom (1954b), one off southern California and northern Baja California (station lines 80–107), the other off central Baja California (station lines 110–137). The upper or northern spawning center was made up of areas 2 (southern California area) and 3 (northern Baja California area) in the above grouping of areas, while the lower or southern spawning center was made up of areas 4 and 5, off central Baja California. The separation of the two centers was most complete in 1951 (Ahlstrom 1954b, fig. 8). This separation was again apparent in 1952 and 1957. The latter is not included in the present report. In intervening years, however, the separation has been less complete, and in 1954, 1955, and 1956, spawning was continuous between the two areas. It is convenient, however, to retain the geographic separation of spawning into two primary centers, or areas, especially since there has been such a marked change in the distribution

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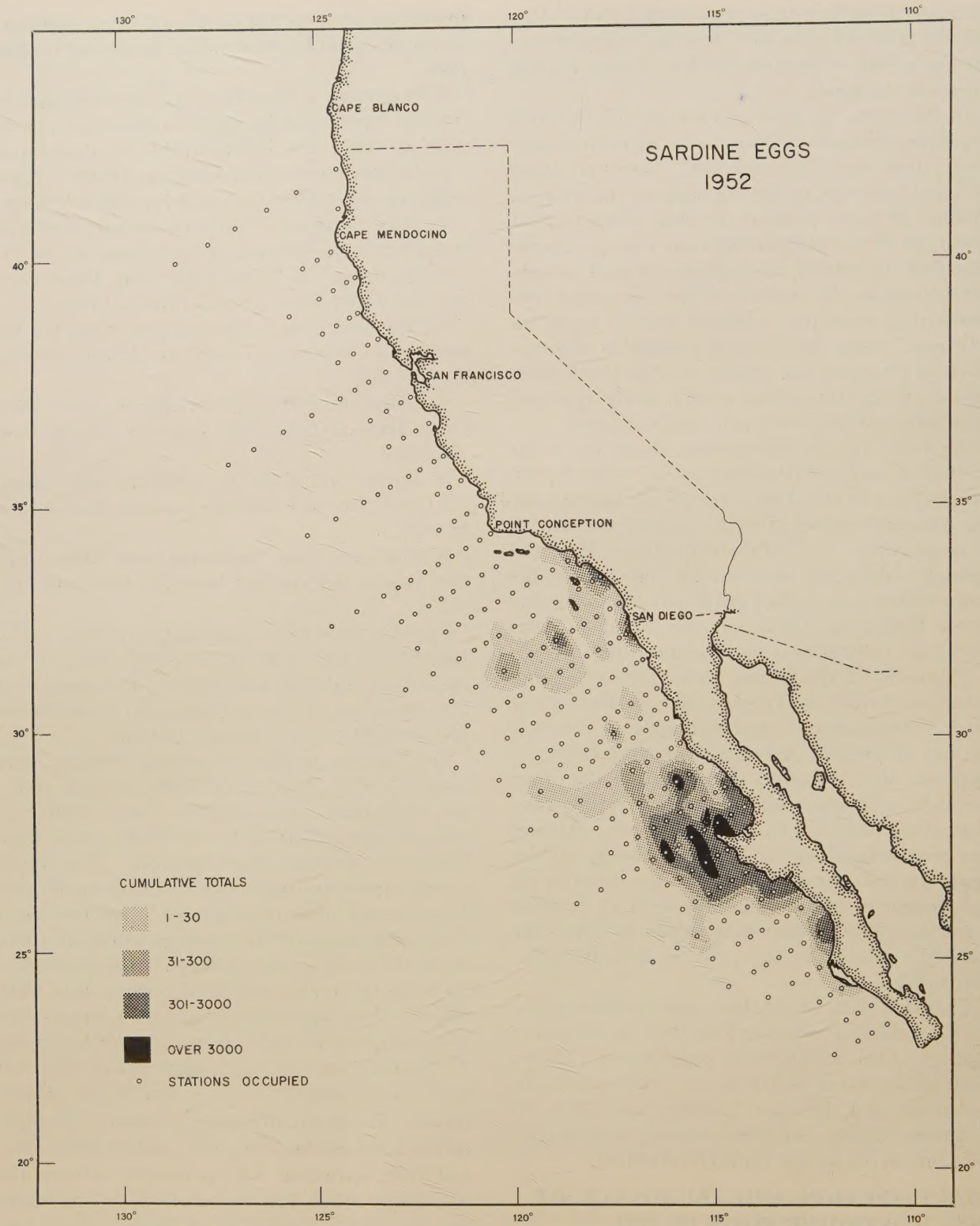

FIGURE 3.—Distribution and abundance of sardine eggs in 1952.

TABLE 2.—*Estimated number of sardine eggs in survey areas, 1952*

[In billions; cruise number in parentheses]

Area	January (5201)	February (5202)	March (5203)	Late March (5203)	April (5204)	May (5205)	June (5206)	July (5207)	August (5208)	September (5209)	October (5210)	November (5211)	Total	Percent
North of Point Conception:														
Lines 40–57							0	0					0	
60–77					0	0	0	0	0	0	0	0	0	
Total					0	0	0	0	0	0	0	0	0	0
Southern California:														
Line 80	0	0	0		0	0	0	0	0	0	0	0	0	
83					0	0	0						0	
85	0	0	0					10	0	0	0	0	10	
87					118	0	0						118	
90	3	0	80		0	613	16	412	8	0	0	0	1,132	
93	0	0	59		378	908	58	0	0	0	0	0	1,403	
Total	3	0	139		496	1,521	74	422	8	0	0	0	2,663	1.96
Northern Baja California:														
Line 97	0	0	471		18	26	67	0	0	0	0	0	582	
100	0	0	0		0	0	4	0	0	0	0	0	4	
103					14	0	0		0	0	0	0	14	
105	0	0	1,030					0					1,030	
107					0	0	0		0	0	0	0	0	
Total	0	0	1,501		32	26	71	0	0	0	0	0	1,630	1.20
Upper central Baja California:														
Line 110	20	0	322		0	0	341	0	0	0	0	0	683	
113		0	16,736	0	3,398	4,251	1,420	74	0	0	0	0	25,879	
115	0								0				0	
117		631	6,765	0	1,135	3,743	2,427	122	119	1,871	0	12	16,825	
120	972	5,280	222	405	10,239	7,422	4,675	1,860	5,512	5,294	0	0	41,881	
Total	992	5,911	24,045	405	14,772	15,416	8,863	2,056	5,631	7,165	0	12	85,268	62.67
Lower central Baja California:														
Line 123	602	203	383	3,249	6,802	2,682	111	66	0	3,024	38	8	17,168	
127	0	0	1,802	4,399	962	554	153	0	0	0	498	0	8,368	
130	848	13	0	156	41	0	0	0	8,819	0	0	0	9,877	
133	0	20	14	0	0	26	0	0	0	0	0	0	60	
137	0	902	0	0	0	0	10,029	0	0	0	0	0	10,931	
Total	1,450	1,138	2,199	7,804	7,805	3,262	10,293	66	8,819	3,024	536	8	46,404	34.11
Southern Baja California:														
Line 140		19											19	
143		64											64	
147		0											0	
150		0											0	
Total		83											83	.06
Grand total	2,445	7,132	27,884	8,209	23,105	20,225	19,301	2,544	14,458	10,189	536	20	136,048	100.00
Percent	1.8	5.2	20.5	6.0	17.0	14.9	14.2	1.9	10.6	7.5	0.4	0	100.0	

of spawning within these centers during the period covered by this report.

There was very little sardine spawning to the north of the central Baja California area in 1952—only 3.2 percent of the total. Sardine spawning in the southern spawning area centered off Point San Eugenio. Less spawning, proportionately, occurred to the south of Point San Eugenio than in 1950 or 1951.

The largest portion of sardine eggs are usually spawned by the 2- and 3-year-old fish, since these ages usually make up the dominant portion of the spawning population. The 1949 and 1950 year classes were the weakest on record, based on numbers landed by the commercial fishery. Each year class supplied only about 130 million fish to the commercial catch. For comparison, it may be noted that the 1939 class supplied 7,500 million fish; the 1947 class, 3,100 million; and the 1948 class, 2,100 million. Undoubtedly, the low egg estimate for 1952 reflects the low numbers of 3-year-old fish of the 1949 class and 2-year-old fish of the 1950 class in the spawning stock.

DISTRIBUTION AND ABUNDANCE OF SARDINE EGGS IN 1953

The estimated abundance of sardine eggs by station lines in 1953 is given in table 3, and the distribution is illustrated in figure 4. Cruises

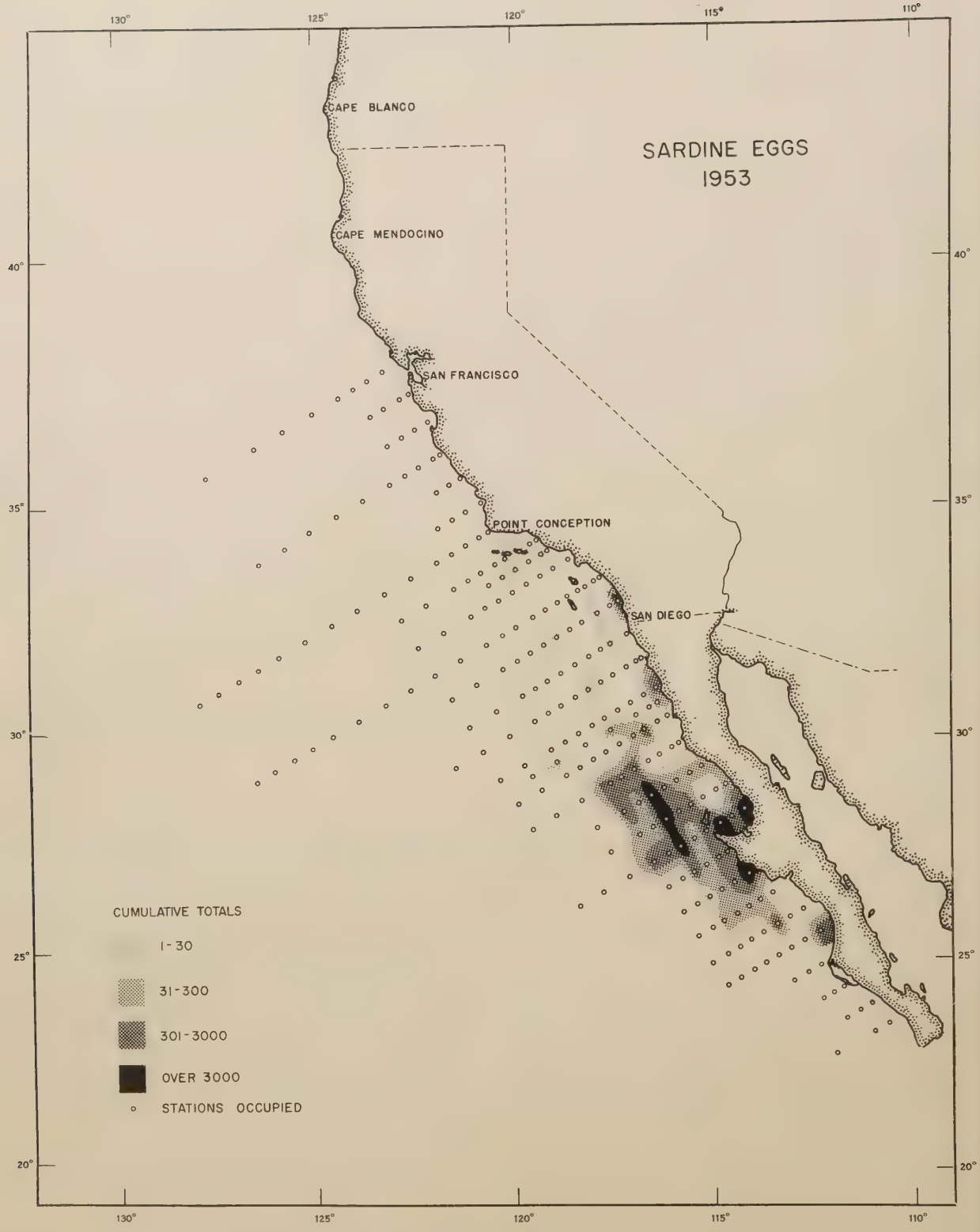

FIGURE 4.—Distribution and abundance of sardine eggs in 1953.

TABLE 3.—*Estimated number of sardine eggs in survey areas, 1953*

[In billions; cruise number in parentheses]

Area	January (5301)	February (5302)	March (5303)	Late March (5303)	April (5304)	May (5305)	June (5306)	July (5307)	August (5308)	September (5309)	October (5310)	November (5311)	December (5312)	Total	Percent
North of Point Conception:															
Lines 60–77					0	0	0	0	0					0	
Total					0	0	0	0	0					0	
Southern California:															
Line 80	0	0	0		0	0	0	0	0					0	
83	0	20	0		0	7	12	0	0	0	0	0	0	39	
85	0	0	0		2	0	0	0	0	0		0	0	2	
87	0	0	0		0	0	0	0	0	0		0	0	0	
90	0	0	0		0	0	0	0	0		0		0	0	
93	0	0	0		0	29	12	593	0		0		0	634	
Total	0	20	0		2	36	24	593	0	0	0	0	0	675	0.15
Northern Baja California:															
Line 97	0	0	0		0	0	18	0	0		0		0	18	
100	0	2	0		0	7	0	0	0		0		0	9	
103					0	981	33	0	0		0		0	1,014	
105	0	671	294											965	
107					1,199	0	0	0	0		0		0	1,199	
Total	0	673	294		1,199	988	51	0	0		0		0	3,205	0.73
Upper central Baja California:															
Line 110	0	0	823		2,298	1,515	0	0	0		0		0	4,636	
113	0	131	9,079	608	1,394	29	2,026	0	0	0	0		432	13,699	
115										0				0	
117	0	21,759	2,480	0	1,083	4,607	1,222	0	77	3,532	0		0	34,760	
120	136	15,497	35	286	10,260	4,022	310	29,047	148,907	4,196	124		1,250	214,070	
Total	136	37,387	12,417	894	15,035	10,173	3,558	29,047	148,984	7,728	124		1,682	267,165	60.70
Lower central Baja California:															
Line 123	0	0	55	568	154	125	0	6,956	382		874		0	9,114	
127	0	2,600	0	23	67	594	13	145,225	213		476		0	149,211	
130	0	406	108	25	0	171	0	0	0		0		0	710	
133	0	0	0	0	0	0	35	0	1,633		0		0	1,668	
137	0	0	0	0	0	0	92	7,871	455		0		0	8,418	
Total	0	3,006	163	616	221	890	140	160,052	2,683		1,350		0	169,121	38.42
Southern Baja California:															
Line 140	0													0	
143	0													0	
147	0													0	
150	0													0	
Total	0													0	0
Grand total	136	41,086	12,874	1,510	16,457	12,087	3,773	189,692	151,667	7,728	1,474	0	1,682	440,166	
Percent	<0.1	9.3	2.9	0.3	3.7	2.8	0.9	43.1	34.5	1.8	0.3	0	0.4	100.0	100.00

were made during all months of 1953, although the cruises in September and November covered only a part of the usual survey area.

The distribution of eggs in 1953 was similar to the distribution in 1952, as can be seen by a comparison of figures 3 and 4. Very little spawning occurred to the north of the central Baja California area—less than 1 percent of the total. Water temperatures were lower during the spring months of 1953 than in any recent season, especially in the inshore waters off southern California and northern Baja California. These data are presented in a later section of this report.

During the first half of 1953, most of the spawning occurred in the upper central Baja California area, offshore from Sebastian Viscaino Bay (station lines 110–120). The heaviest spawning of the year, however, occurred in July and August, centered within Sebastian Viscaino Bay and along shore in the area between Point San Eugenio and Point San Juanico. This late-season spawning was the heaviest of any recent year.

DISTRIBUTION AND ABUNDANCE OF SARDINE EGGS IN 1954

The distribution of sardine eggs in 1954 is shown in figure 5; their estimated abundance in table 4. Ten cruises were made in 1954, representing every month except September and November. As can be seen from the spacing of stations in figure 5, a more intensive survey of spawning areas was made in 1954 than in previous years.

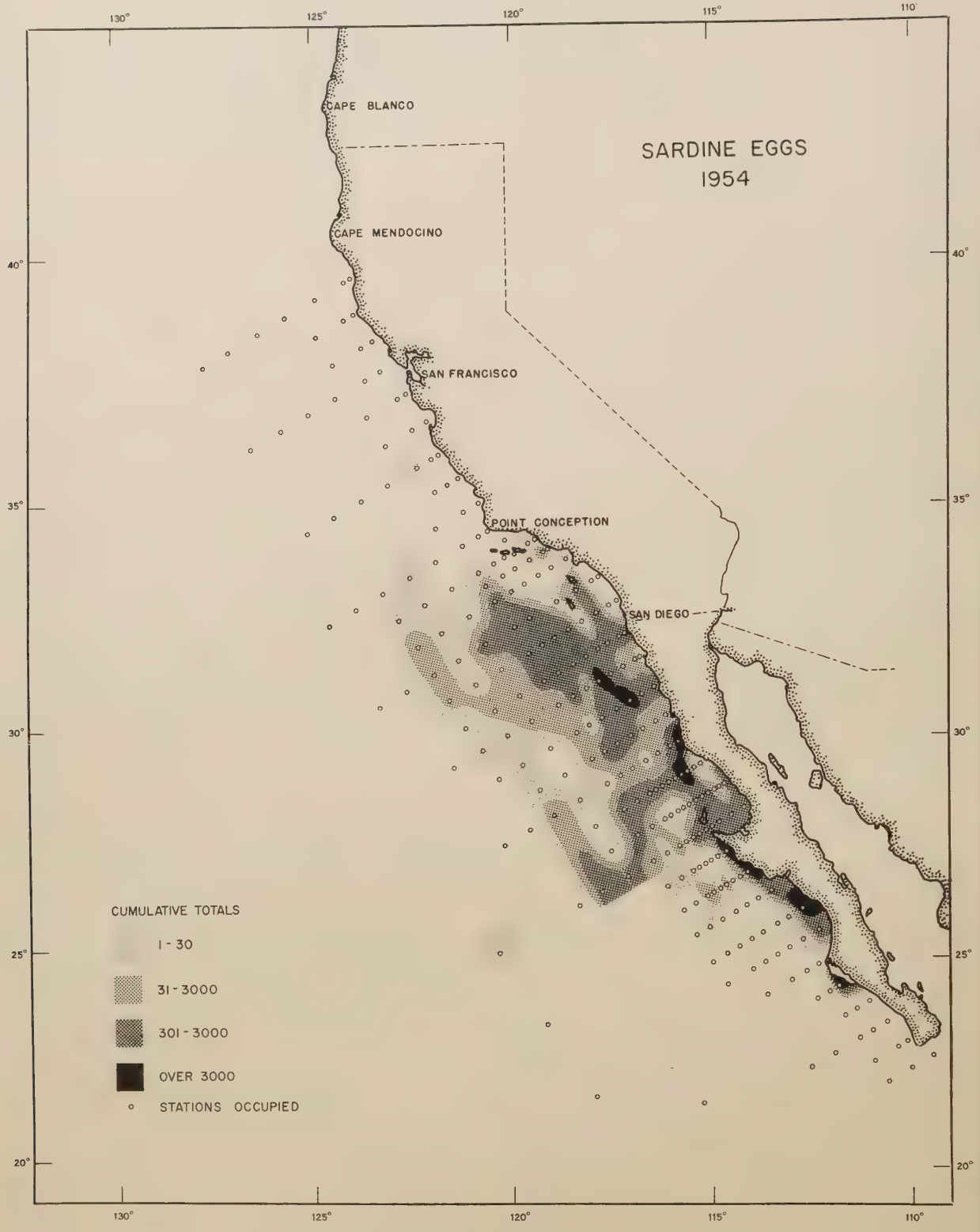

FIGURE 5.—Distribution and abundance of sardine eggs in 1954.

TABLE 4.—*Estimated number of sardine eggs in survey areas, 1954*

[In billions; cruise number in parentheses]

Area	January (5401)	February (5402)	March (5403)	April (5404)	May (5405)	June (5406)	July (5407)	August (5408)	October (5410)	December (5412)	Total	Percent
North of Point Conception:												
Lines 60–77	0	0	0	0	0	38	0	0	0		38	0.01
Total	0	0	0	0	0	38	0	0	0		38	0.01
Southern California:												
Line 80	0	0	0	0	0	67	0	0	0	0	67	
83	0	17	0	0	99	132	7	0	0	0	255	
85	0	2	2	3	0	75	385	0	0	0	467	
87	0	0	0	268	4, 559	197	19	0	0	0	5, 043	
90	0	0	0	1, 801	1, 093	6, 662	11, 317	0	0	0	20, 873	
93	0	0	0	3, 214	6, 661	10, 576	0	0	0	0	20, 451	
Total	0	19	2	5, 286	12, 412	17, 709	11, 728	0	0	0	47, 156	13. 27
Northern Baja California:												
Line 97	0	0	4, 174	7, 254	1, 561	13, 215	128	170	0	0	26, 502	
100	2	0	2, 725	972	16, 538	4, 217	139	0	0	0	24, 593	
103	39	10	4, 096	15, 951	3, 251	1, 672	5, 714	0	0	0	30, 733	
107	0	40	604	2, 798	278	4, 045	37	0	0	0	7, 802	
Total	41	50	11, 599	26, 975	21, 628	23, 149	6, 018	170	0	0	89, 630	25. 22
Upper central Baja California:												
Line 110	26	110	1, 207	3, 950	5, 371	334	0	0	0	0	10, 998	
113	0	6, 022	10, 037	8, 128	3, 860	2, 949	0	0	0	0	30, 996	
117	26	461	3, 883	941	4, 365	101	241	0	0	0	10, 018	
120	21, 595	6, 660	8, 752	268	94	338	8, 016	7, 252	0	232	53, 207	
Total	21, 647	13, 253	23, 879	13, 287	13, 690	3, 722	8, 257	7, 252	0	232	105, 219	29. 61
Lower central Baja California:												
Line 123	3, 431	27, 879	3, 593	88	0	0	643	13	0	200	35, 847	
127	380	9, 235	4, 652	407	108	22	324	0	0	0	15, 128	
130	0	28	0	0	0	12	2, 285	0	0	0	2, 325	
133	0	48	0	0	0	0	40, 297	0	0	0	40, 345	
137	44	0	0	0	2, 142	1, 418	0	0	0	141	3, 745	
Total	3, 855	37, 190	8, 245	495	2, 250	1, 452	43, 549	13	0	341	97, 390	27. 41
Southern Baja California:												
Line 140	0									0	0	
143	15, 925									0	15, 925	
147	0									0	0	
150	0									0	0	
Total	15, 925									0	15, 925	4. 48
Grand total	41, 468	50, 512	43, 725	46, 043	49, 980	46, 070	69, 552	7, 435	0	573	355, 358	100. 00
Percent	11. 7	14. 2	12. 3	13. 0	14. 1	13. 0	19. 6	2. 1	0	0. 2	100. 2	

The most striking feature of sardine spawning in 1954 was its northward spread to waters off southern California and northern Baja California. It is by far the greatest contrast that has been observed between successive seasons. In 1953, sardine eggs were obtained in only 20 hauls in the northern center (station lines 80–107), while in 1954 they were taken in 149 hauls. In 1953, the distribution was discontinuous; in only two instances were sardine eggs taken in contiguous hauls. In 1954, the distribution was continuous over widespread areas. Only 4×10^{12} eggs are estimated to have been spawned in the northern center in 1953, while 137×10^{12} are estimated to have been spawned in 1954. Interpreting these figures literally, there were approximately 35 times as many spawning fish in the northern center in 1954 as in 1953.

The estimate of egg abundance for the area off central Baja California of 203×10^{12} eggs constitutes approximately 57 percent of the total number taken during 1954. The late-season spawning was much less important in 1954 than in 1953; less than 30 percent of the estimated total number of eggs in the central Baja California region was obtained during the last half of the year.

DISTRIBUTION AND ABUNDANCE OF SARDINE EGGS IN 1955

The estimated abundance of sardine eggs in 1955 is summarized by month and station line in table 5. Relative abundance in different parts of the spawning area is illustrated in figure 6. The August cruise of 1955, the wide-ranging Norpac expedition, is not included in the tabulations. No sardine eggs and only 27 sardine larvae were obtained on Norpac.

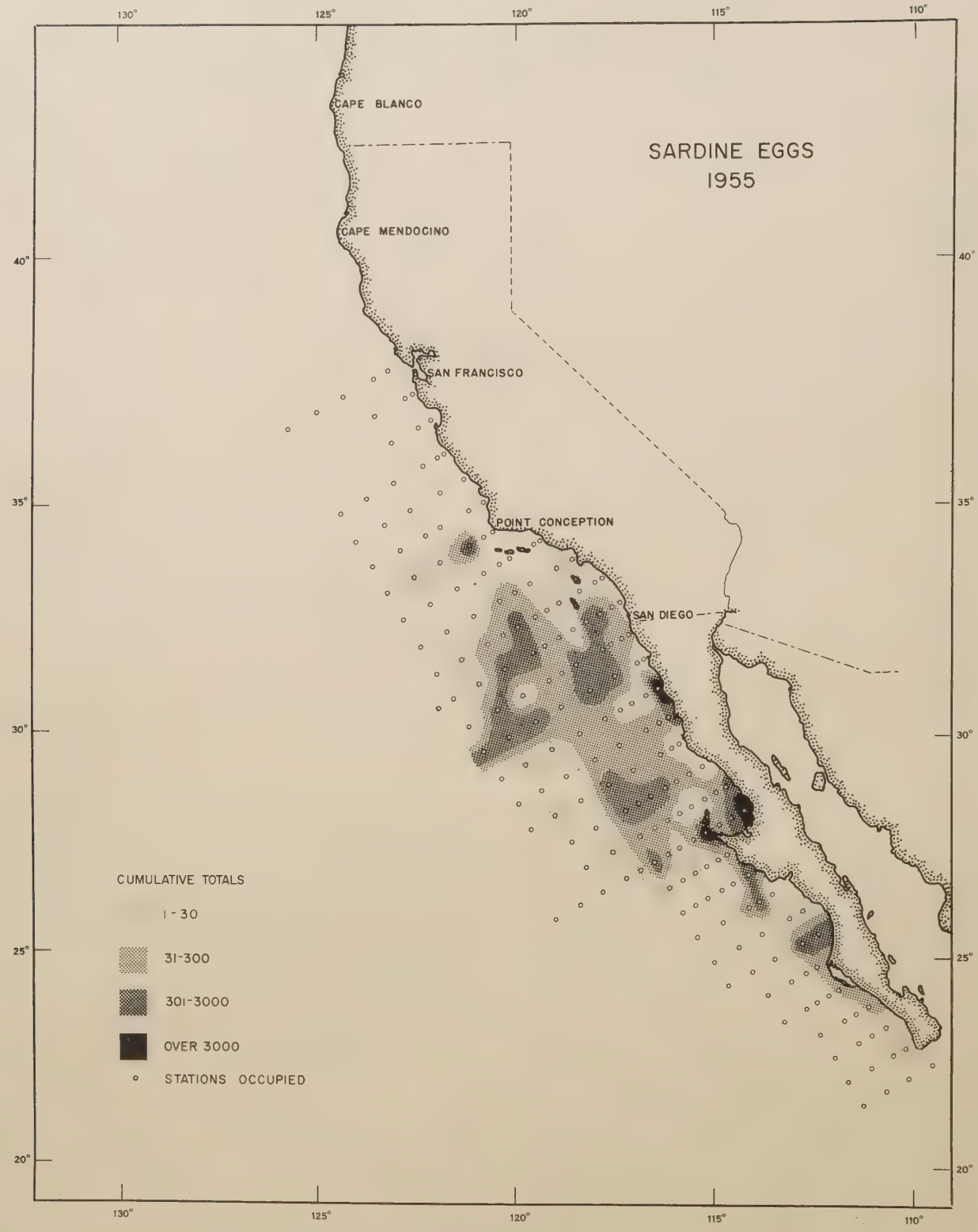

FIGURE 6.—Distribution and abundance of sardine eggs in 1955.

TABLE 5.—*Estimated number of sardine eggs in survey areas, 1955*

[In billions; cruise number in parentheses]

Area	January (5501)	February (5502)	March (5503)	April (5504)	May (5505)	June (5506)	July (5507)	August (5508) [1]	September (5509)	October (5510)	November (5511)	December (5512)	Total	Percent
North of Point Conception:														
Lines 60–77					0	0	0			0			0	
Total					0	0	0			0			0	0
Southern California:														
Line 80	0	0	0	0	0	4,379	0			0		0	4,379	
83	0	0	0	0	0	0	0		0	0	0	0	0	
87	0	0	0	0	0	309	56		0	0	0	0	365	
90	0	0	250	278	1,031	277	40		0	0	0	0	1,876	
93	0	0	1,511	64	6,153	3,714	0			0		0	11,442	
Total	0	0	1,761	342	7,184	8,679	96		0	0	0	0	18,062	11.11
Northern Baja California:														
Line 97	0	0	1,342	11,288	10,101	572	0			0		0	23,303	
100	0	0	4,687	23,690	2,152	33	0			0		0	30,562	
103	0	6,268	60	1,277	147	48	36			0		8	7,844	
107	9	3,117	579	2,188	34	17	0			0		0	5,944	
Total	9	9,385	6,668	38,443	12,434	670	36			0		8	67,653	41.60
Upper central Baja California:														
Line 110	0	2,838	165	263	7	0	0			0		0	3,273	
113	12,238	4,910	4,424	675	0	0	0			0		0	22,247	
117	18	119	526	622	1,122	299	259			240		0	3,205	
120	5,280	871	1,382	9	6,693	6,505	4,234			1,972		377	27,323	
Total	17,536	8,738	6,497	1,569	7,822	6,804	4,493			2,212		377	56,048	34.46
Lower central Baja California:														
Line 123	47	0	32	0	0	0	17			0		433	529	
127	0	0	0	0	0	0	0			0		1,834	1,834	
130	0	0	0	0	0	0	6,028			0		0	6,028	
133	0	0	0	0	0	21	0			62		0	83	
137	2,697	0	0	0	8,230	0	0			0		0	10,927	
Total	2,744	0	32	0	8,230	21	6,045			62		2,267	19,401	11.93
Southern Baja California:														
Line 140	0	0	0									0	0	
143	0	434	0									0	434	
147	939	0	0									0	939	
150	58	0	0									0	58	
153	47	0	0										47	
157	0	0	0										0	
Total	1,044	434	0									0	1,478	0.91
Grand total	21,333	18,557	14,958	40,354	35,670	16,174	10,670		0	2,274	0	2,652	162,642	100.01
Percent	13.1	11.4	9.2	24.8	21.9	9.9	6.6		0	1.4	0	1.6	99.9	

[1] Norpac.

The distribution of eggs in 1955 was almost as widespread as in 1954. More than 50 percent of the eggs were obtained in the northern center, with the heaviest spawning occurring on lines 93–100, between Del Mar, Calif., and Ensenada, Baja California.

There were only 18 occurrences of sardine eggs to the south of Point San Eugenio during 1955 (lower central Baja California area). This represented a marked decrease from preceding seasons. Only about 13 percent of the spawning occurred in this area in 1955 as compared with 52 percent in 1951, 34 percent in 1952, 38 percent in 1953, and 27 percent in 1954.

The late-season spawning (July to December) was not adequately sampled in 1955. The only regular cruises made off central Baja California after July were in October and December. Because of this, the 1955 estimate is too low by perhaps 10 or 15 percent.

DISTRIBUTION AND ABUNDANCE OF SARDINE EGGS IN 1956

The survey area in 1956 was covered fairly completely during January through July, but only partially thereafter. The area between Point Conception, Calif., and Point San Juanico, Baja California (lines 80–137), was covered on monthly cruises between January and July 1956; the area to the north of Point Conception (lines 60–77) was covered in April through June; the area off southern Baja California in January, February,

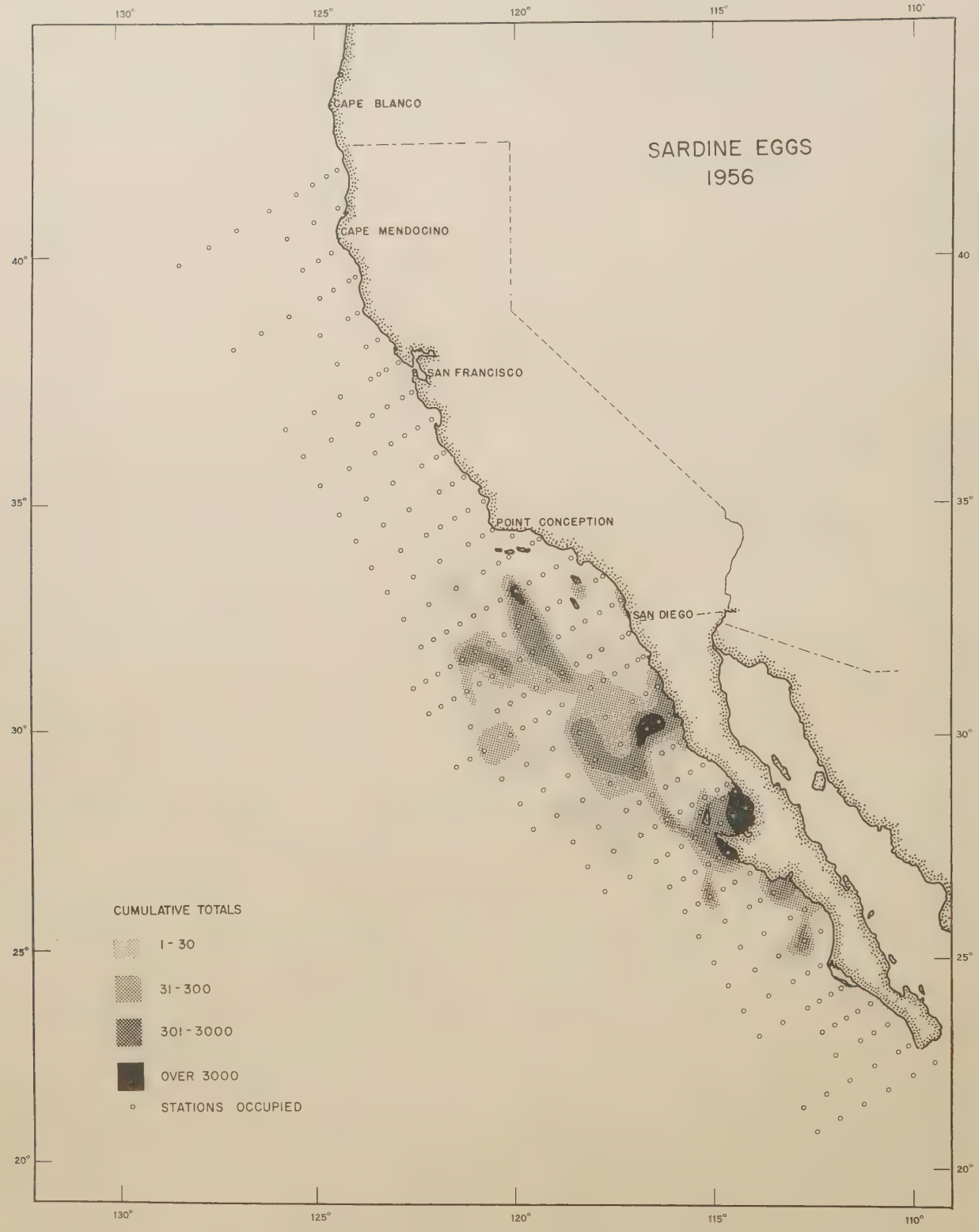

FIGURE 7.—Distribution and abundance of sardine eggs in 1956.

and April. After July, the cruises covered only a portion of the usual survey area: in August and September the portion off central Baja California; in October through December the portion off southern California and one station line off northern Baja California (lines 80–97).

The distribution of sardine eggs in 1956 (fig. 7) was similar to that in 1954, although areas of high concentration of eggs were less widespread. The heaviest spawning in 1956 was in the Sebastian Viscaino Bay region in July (table 6). The percentage of spawning that occurred in the northern center was lower than in the preceding year: 37.3 percent in 1956, as compared with 52.7 percent in 1955. Spawning in the northern spawning center, however, had a wider distribution than in the southern center (table 7).

The 1956 season was unusual in several respects. There was less difference in temperatures in different parts of the spawning range than in any recent year (table 12); furthermore, the temperatures throughout the spawning range were the lowest of any year between 1951 and 1956.

AREAL DISTRIBUTION OF SPAWNING

The marked change in the distribution of sardine spawning that occurred between the 1953 and 1954 seasons has been briefly commented on in the discussion of the distribution and abundance of sardine eggs in 1954. This difference will be

TABLE 6.—*Estimated number of sardine eggs in survey areas, 1956*

[In billions; cruise number in parentheses]

Area	January (5601)	February (5602)	March (5603)	April (5604)	May (5605)	June (5606)	July (5607)	August (5608)	September (5609)	October (5610)	November (5611)	December (5612)	Total	Percent
North of Point Conception:														
Lines 60–77				0	0	0							0	
Total				0	0	0							0	0
Southern California:														
Line 80	0	0	0	0	0	0	0			0	0	0	0	
83	0	0	0	16	0	0	0			0	0	0	16	
87	0	0	0	0	44	8,631	10			0	0	0	8,685	
90	0	0	39	0	12,123	480	364			0	0	0	13,006	
93	0	0	38	0	6,379	1,043	0			83	0	0	7,543	
Total	0	0	77	16	18,546	10,154	374			83	0	0	29,250	11.43
Northern Baja California:														
Line 97	0	0	261	48	2,378	120	9			0	0	0	2,816	
100	0	0	93	2,490	442	0	0						3,025	
103	0	27	2,125	3,032	96	17,241	700						23,221	
107	0	0	4,707	136	44	26,456	5,923						37,266	
Total	0	27	7,186	5,706	2,960	43,817	6,632			0	0	0	66,328	25.91
Upper central Baja California:														
Line 110	0	10	1,669	2,216	9	0	0	0	0				3,904	
113	0	90	286	85	0	0	0	0	0				461	
115								0	0				0	
117	4	5,606	0	17	580	0	29	13,102	0				19,338	
120	2,588	576	6,560	17	9,732	186	64,133	9,418	6,520				99,730	
Total	2,592	6,282	8,515	2,335	10,321	186	64,162	22,520	6,520				123,433	48.22
Lower central Baja California:														
Line 123	0	5,910	2,054	366	0	0	0	0	0				8,330	
127	0	39	0	16,013	0	0	0	0	0				16,052	
130	0	1,230	0	0	0	0	0	0	0				1,230	
133	0	0	0	0	0	0	0	1,063	0				1,063	
137	0	0	0	0	0	10,156	0	0	0				10,156	
Total	0	7,179	2,054	16,379	0	10,156	0	1,063	0				36,831	14.39
Southern Baja California:														
Line 140	0	0		0									0	
143	82	0		0									82	
147	0	75		0									75	
150	0	0		0									0	
153	0	0		0									0	
157	0	0		0									0	
Total	82	75		0									157	0.06
Grand total	2,674	13,563	17,832	24,436	31,827	64,313	71,168	23,583	6,520	83	0	0	255,999	100.01
Percent	1.0	5.3	7.0	9.6	12.4	25.1	27.8	9.2	2.6	<0.1	0	0	100.0	

further developed by considering the areal distribution of spawning in the northern and southern spawning centers during 1952 through 1956.

The areal extent of spawning has been estimated for each spawning center by cruise. The results are summarized in table 7. Yearly summaries based on the summation of areal distributions of monthly cruises follow:

Year	Northern center (lines 80–107)	Southern center (lines 110–137)	Total
	Square miles	*Square miles*	*Square miles*
1952	27, 824	89, 920	117, 744
1953	14, 560	90. 224	104, 784
1954	149, 904	137, 680	287, 584
1955	120, 912	76. 208	197, 120
1956	80, 368	55, 120	135. 488

The areal extent of sardine spawning in 1954 was 2.7 times as great as in 1953. Compared with the distribution in 1952 it was 2.4 times as great, 1.5 times as great as in 1955, and 2.1 times as great as in 1956. There was not only a tenfold increase in the extent of spawning in the northern center (lines 80–107) in 1954 as compared with 1953, but there was an increase in the area over which spawning extended in the southern center (lines 110–137), as well.

Not only was sardine spawning spread over a greater area in 1954 than in any other year in the series, there was also a greater extent of moderately heavy to very heavy concentrations of eggs (101 or more eggs per standard area per day) than in other years (refer to table 8). This point is illustrated in figure 8. The moderately heavy to very heavy categories of table 8 are grouped together in this figure as heavy, while the light and moderate categories of table 8 are designated as light. In 1954, the extent of heavy spawning was greater in both the northern and southern spawning areas than in the other years.

There are two possible explanations for the marked increase in spawning in the northern center in 1954: either the sardines moved into the area from another area or areas, or the sardines had been in the northern center all of the time, but few of them had spawned in 1952 and 1953.

TABLE 7.—*Estimated area over which sardine spawning took place summarized by cruise for the northern and southern centers, 1952–56*

[In square miles]

	Northern center (lines 80–107)					Southern center (lines 110–137)				
	1952	1953	1954	1955	1956	1952	1953	1954	1955	1956
January	256	0	752	720	0	5, 840	960	28, 656	13, 440	1, 696
February	0	1, 600	1, 728	7, 936	1, 200	10, 960	11, 360	24, 976	10, 496	12, 976
March	7, 712	4, 800	26, 784	26, 480	28, 096	11, 248	16, 672	25, 792	14, 800	15, 616
April	8, 336	1, 840	44, 640	39, 856	15, 824	15, 824	14, 000	20, 144	14, 160	7, 968
May	5, 680	3, 120	33, 400	22, 416	20, 800	14, 144	14, 592	14, 128	5, 088	3, 296
June	3, 520	2, 880	36, 392	21, 360	11, 312	13, 104	10, 464	12, 160	3. 792	6, 128
July	1, 520	320	5, 760	1, 568	2, 816	4, 704	4, 688	6, 800	5, 648	2, 256
August	800	0	448	Norpac		7, 360	8, 880	2, 928	Norpac	3, 984
September	0	0		0		4, 560	3, 712			1, 200
October	0	0	0	0	320	1, 200	1, 872	0	5, 152	
November	0	0		0	0	976				
December		0	0	576	0		3, 024	2, 096	3. 632	
Total	27, 824	14, 560	149, 904	120, 912	80, 368	89, 920	90, 224	137, 680	76, 208	55, 120

TABLE 8.—*Relative areal distribution of sardine spawning, grouped according to intensity of spawning in the northern and southern centers, 1952–56*

[In square miles]

Abundance	Number of eggs per standard area per day	Northern center (lines 80–107)					Southern center (lines 110–137)				
		1952	1953	1954	1955	1956	1952	1953	1954	1955	1956
Light	1–10	19, 984	9, 040	72, 728	58, 480	42, 960	30, 624	30, 752	67, 816	39, 808	28, 784
Moderate	11–100	7, 584	3, 920	44, 312	41. 296	22, 222	33, 584	29, 712	33, 088	17, 280	11, 024
Moderate heavy	101–1,000	256	1, 600	31. 264	20, 560	13. 168	23, 712	23, 856	32. 456	18, 128	11. 808
Heavy	1,001–10,000	0	0	1, 600	576	2, 018	2, 000	4, 080	4, 320	992	3, 504
Very heavy	Over 10,000	0	0	0	0	0	0	1, 824	0	0	0
Total		27, 824	14, 560	149, 904	120, 912	80, 368	89, 920	90, 224	137, 680	76, 208	55, 120

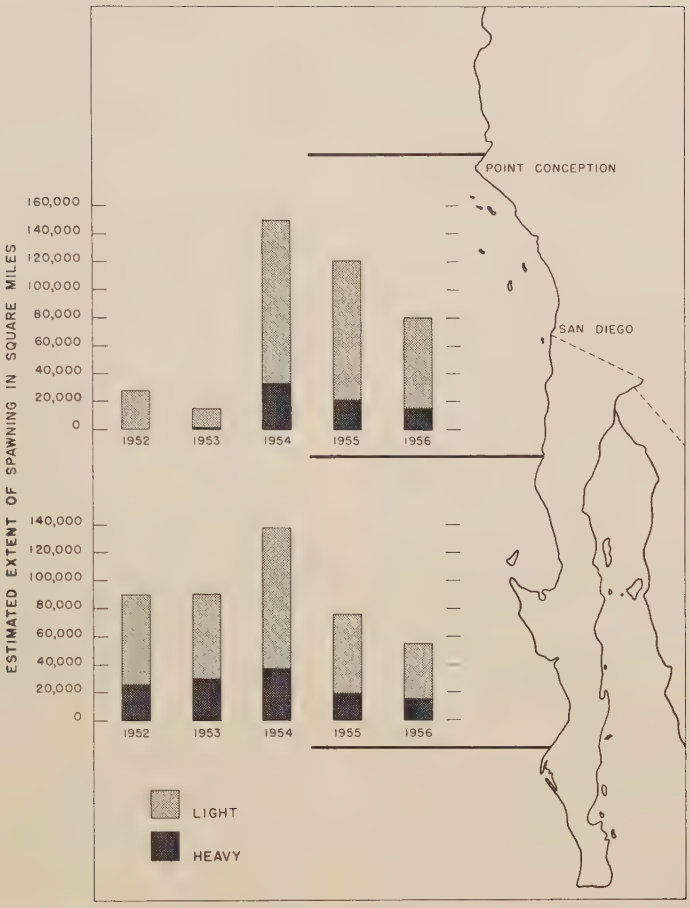

FIGURE 8.—Estimated relative areal extent of spawning in the northern (lines 80–107) and southern centers (lines 110–137).

The second alternative is not supported by evidence from the fish catch. The commercial catch of sardines pointed to a very low abundance in the northern center in 1952 and 1953. The commercial catch (in California) in 1952–53 amounted to only 4,520 tons, in 1953–54 to 3,172 tons, while it jumped to 67,258 tons in 1954–55.

Emigration into the area is the only explanation that satisfactorily accounts for both the increase in eggs spawned in the northern center in 1954 and the marked increase in fish available to the fishery in the 1954–55 season. The only likely areas that sardines could have migrated from are those to the south. There seems to be little doubt, therefore, that sardines moved into the northern spawning center from the southern center off central Baja California.

There is no categorical answer to the question, "Why did the spreading out of spawning occur?" At least two explanations should be given careful consideration: (1) The movement was a result of change in environmental conditions, and (2) the movement was the result of population pressure.

If the change in distribution resulted from a change in the physical environment that favored emigration, the most likely change would involve water temperatures, directly, or as an indicator of other qualities of significance to spawning sardines.

In order to study temperature changes within the northern spawning center, the area was divided into four quadrants. The northeast section (inshore, southern California) was identical to the area surveyed in 1940 and 1941; the northwest portion consisted of all stations occupied on lines 80–93 to the seaward of the inshore section. The southeast portion consisted of all stations on lines 97 to 107 between shore and station 50 inclusive; the offshore quadrant comprised all stations occupied to the seaward of station 50 on lines 97–107.

Average temperatures at a depth of 10 meters for the winter and spring seasons of 1951 through 1956 are given in table 9 for the four quadrants of the northern spawning center. There was nothing unusual about winter and spring temperatures in 1954. For the northern center as a whole, the winter temperatures were less than 0.1° C. higher than the 6-year average; the spring temperatures were 0.25° C. higher than the average. In the sections contiguous to the southern spawning center, the southeast and southwest areas that emigrating sardines would first enter, the temperatures were somewhat above average in the inshore quadrant (0.17° C. in January–March and 0.50° C. in April–June) and somewhat below average in the offshore quadrant in the winter period (0.25° C. lower than average) and close to average in the spring period. There was only 0.02° C. difference between the average winter temperatures in the northern spawning center in 1952 as compared with 1954—two markedly contrasting years with regard to distribution and abundance of spawning in the northern center. Temperatures in 1953, the year with the least spawning in the northern center, were not much below average in the winter period (0.11° C.), but were the coldest in the series during the spring months (0.61° C. below the 6-year average).

TABLE 9.—*Average water temperatures at a depth of 10 meters in northern spawning center based on all stations occupied*

[Lines 80–107]

Date	Temperature (° C.) in—				
	Northeast section	Northwest section	Southeast section	Southwest section	Northern center
January–March:					
1951	13.34	14.92	14.72	15.87	14.71
1952	13.59	13.86	14.41	15.08	14.24
1953	13.33	13.98	14.24	14.71	14.06
1954	13.90	13.93	14.46	14.73	14.26
1955	13.46	13.67	14.26	14.72	14.03
1956	12.79	13.78	13.65	14.67	13.72
Average	13.40	14.02	14.29	14.96	14.17
April–June:					
1951	14.34	14.51	15.46	16.14	15.11
1952	14.09	14.75	14.23	16.16	14.81
1953	12.90	14.29	14.16	15.57	14.23
1954	14.20	14.75	15.52	15.90	15.09
1955	14.28	14.21	15.63	15.70	14.96
1956	14.22	14.30	15.10	15.76	14.84
Average	14.00	14.47	15.02	15.87	14.84

Temperature data for the years 1952 through 1956 will be published in Oceanic Observations of the Pacific, of which only one volume in the series, observations for 1949, has appeared as yet (Rakestraw, Horrer, and Wooster, 1957).

In a subsequent section, there is a discussion of temperatures at which sardine eggs were obtained during the years 1951 through 1956. I do not wish to anticipate results before presenting the data, but the difference was more marked between temperatures at which sardine eggs were obtained in the two major spawning centers in 1952 and 1953 than in the other years.

An alternative explanation for the emigration is that population pressure had increased to such an extent in the southern center that a portion of the population moved out. Some data can be marshaled in support of this thesis, some against it. Two lines of evidence will be considered: virtual population estimates and estimates of the number of eggs spawned.

It is possible to derive minimal estimates of the size of the spawning population each year from virtual population (accumulated age) estimates. These estimates are based on age composition data from the commercial catch (Felin, Anas, Daugherty, and Pinkas, 1952; Felin, MacGregor, Daugherty, and Miller, 1953, 1954, and 1955; Felin, Wolf, Daugherty, and Miller, 1958; Wolf, MacGregor, Daugherty, and Miller, 1958). Each estimate represents those sardines of 2 years of age and older that were definitely present in the population in a given season, since they were subsequently caught. Availability influences virtual population estimates, since only those fish can be caught that are present in the fishing area. Also, differences in fishing intensity and natural mortality of sardines are not taken into account. Hence, the estimates are minimal.

Virtual population estimates for seasons 1951 through 1955 are compared with estimates of sardine egg abundance in the following tabulation. Recent estimates of the virtual population are low, because some year classes used in the estimates have made only a partial contribution to the fishery as yet. The 1956 estimate of the virtual population is not included for this reason.

Year	Virtual population estimate (in billions) [1]	Estimate of sardine egg abundance
1951	1.20	610×10^{12}
1952	.38	136×10^{12}
1953	.67	436×10^{12}
1954	1.17	355×10^{12}
1955	0.75	163×10^{12}

[1] Minimal size of spawning population.

There is fair correspondence between the virtual population estimates and the estimates of sardine egg abundance for every season except 1953. In this season the estimate of egg abundance is too large in comparison with the virtual population estimate. As noted previously, most of the sardine eggs obtained in 1953 resulted from fall spawning in the southern center, and it is unlikely that the group of late-season spawners ever became fully available to the California fishery. Only about 89×10^{12} eggs were taken during the main spawning period in 1953 (table 12).

The virtual spawning population in 1954 was the largest for any season since 1951. The increase could have resulted in moderate population pressure. However, the amount of spawning off central Baja California in 1954 was only 35 percent as much as in 1951, when spawning remained concentrated in the southern spawning center.

The widespread spawning in 1954 is interesting for another reason. In a consideration of factors that might favorably influence the survival of a year class, I have theorized (Ahlstrom 1950, p. 45) that the extent of the area over which spawning was spread was probably one of the more important ones: the larger the area, the greater the chance of a good survival. The 1954 distribution gave us an opportunity to test this hypothesis. The areal extent of sardine spawning in 1954 was greater than in any other recent year. The 1954 class had poor survival during the larval stage and has, to date, contributed very little to the fishery (larval survival for 1952–56 classes will be presented in a later publication). It appears to be nearly as weak as the very poor 1949 and 1950 classes, and has contributed only 85 million fish to the catch as 1- to 3-year-old fish. If this judgment is born out by its subsequent history in the fishery, then we must question the importance of wide areal distribution in the production of a successful year class.

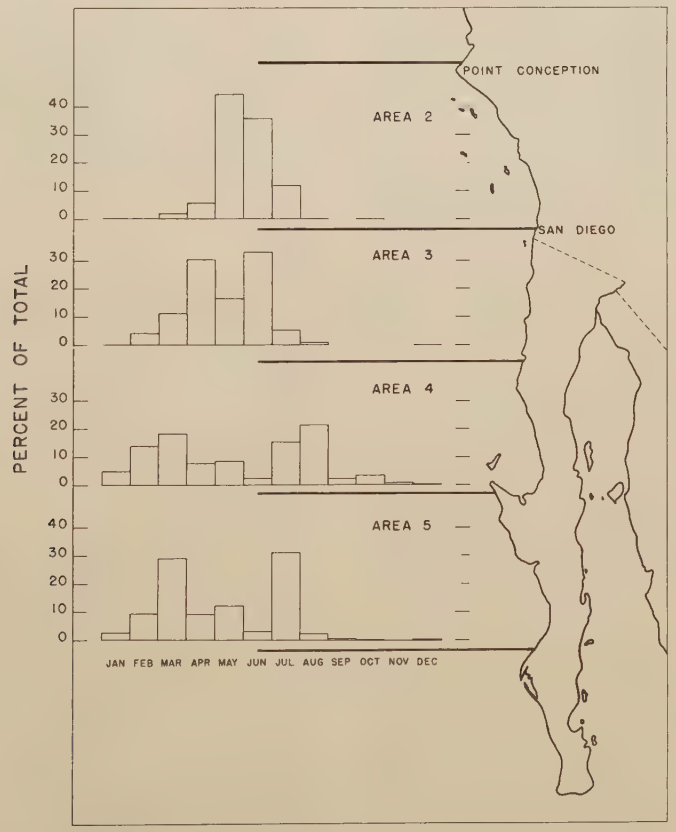

FIGURE 9.—Average seasonal distribution of sardine spawning, 1951–56, by area. (Area 1 omitted; see footnote to table 10.)

The relation between sardine spawning in the northern center and availability of sardines to the commercial fishery during the subsequent fishing season has been briefly mentioned for 1952 through 1954. The relation during the 5-year period, 1952 through 1956, is given in the following tabulation:

Spawning season	Estimated abundance of eggs in northern spawning center	Percentage of total spawning	Commercial fishing season (Oct. 1–Feb. 1)	California commercial catch (tons)
1952	4×10^{12}	3.2	1952–53	4,520
1953	4×10^{12}	.9	1953–54	3,170
1954	137×10^{12}	38.5	1954–55	67,260
1955	86×10^{12}	52.7	1955–56	74,960
1956	96×10^{12}	37.3	1956–57	32,650

Sardine spawning was negligible in the northern center in 1952 and 1953, and the commercial catch was exceedingly poor. With the return of a sizable spawning population to the northern spawning center in 1954, the commercial catch immediately jumped to 67,260 tons. It could have been larger during this season, as a price dispute delayed the opening of the San Pedro season for about 5 weeks. The 1955–56 catch was the best during the 5-year period. The catch during the 1956–57 season started out well. Sardines were moving southward during the brief period of good fishing and were not available in any numbers to the southern California fishery during the remainder of the season.

SEASONAL DISTRIBUTION OF SPAWNING 1951–56

The monthly occurrences and abundance of sardine eggs in different parts of the spawning range are summarized in table 10 for the 6-year period, 1951–56. Average seasonal distributions are illustrated in figure 9. The 1950 season is not included because the coverage of spawning areas was less intensive and complete than in succeeding years.

Southern California area (lines 80–93)

Approximately 98 percent of the eggs spawned in this area have been obtained during the 4-month period, April through July. The month of peak spawning has been either May (1951, 1952, 1956), June (1954, 1955), or July (1953). Based on totals for six seasons (1951–56), nearly 45 percent of the sardine eggs were obtained in May, 35 percent in June. There have been only three occurrences of sardine eggs in the months of August through January. Some spawning has taken place during February and March, but it usually has been light; about 10 percent of the occurrences off southern California were recorded for these months, but only about 2 percent of the number of eggs spawned.

Northern Baja California area (lines 97–107)

The areas off southern California and northern Baja California together constitute the northern spawning center. As off southern California, there have been only negligible amounts of spawning during August through January (six occurrences, 0.11 percent of eggs spawned). Spawning has occurred somewhat earlier in the year off northern Baja California, however. More than 45 percent of the sardine eggs were obtained during February through April in this area, whereas less than 8 percent were obtained during these months off southern California. Since 1954, there have been considerably more occurrences of eggs in this area than off southern California. Based on totals for the six seasons, approximately 30 percent of sardine eggs were obtained in April and 33 percent in June.

Upper central Baja California area (lines 110–120)

Sardine eggs have been collected throughout the year in this area. The composite seasonal distribution, based on the totals for 6 years, is bimodal, with peaks in March and August. Spawning during the first half of the year usually has a much wider areal distribution than spawning during the latter half. As is shown later, spawning during the main spawning period has taken place at temperatures that were only slightly higher than those encountered in the northern spawning center, but that were fully 2.5° C. lower than the average temperature of spawning of the late-season group.

Late-season spawning usually is confined to the southern end of Sebastian Viscaino Bay in the upper central Baja California area (lines 110–120) and to inshore stations along the coast in the lower central Baja California area (lines 123–137). As is pointed out later, late-season spawners may constitute a separate subpopulation of

TABLE 10.—*Occurrences and abundance of sardine eggs, by area and month, 1951–56*

Area [1] and month	Occurrence of eggs							Estimated number of eggs (in billions)							
	1951	1952	1953	1954	1955	1956	Total	1951	1952	1953	1954	1955	1956	Total	Percent
Southern California (lines 80–93):															
January	0	1	0	0	0	0	1	0	3	0	0	0	0	3	<0.01
February	1	0	2	2	0	0	5	0	0	20	19	0	0	39	.03
March	2	3	0	1	3	3	12	211	139	0	2	1,761	77	2,190	1.93
April	6	4	1	13	5	1	30	202	496	2	5,286	342	16	6,344	5.59
May	4	7	3	18	14	14	60	10,927	1,521	36	12,412	7,184	18,546	50,626	44.59
June	6	2	3	18	15	8	52	4,065	74	24	17,709	8,679	10,154	40,705	35.89
July	3	2	1	5	2	2	15	315	422	593	11,728	96	374	13,528	11.96
August	0	1	0	0	(2)		1	0	8	0	0			8	.01
September	0	0	0		0		0	0	0	0		0		0	0
October	0	0	0	0	0	1	1	0	0	0	0	0	83	83	.07
November	0	0	0			0	0	0	0	0		0	0	0	0
December	0		0	0	0	0	0	0		0	0	0	0	0	0
Total	22	20	10	57	39	29	177	15,720	2,663	675	47,156	18,062	29,250	113,526	100.00
Northern Baja California (lines 97–107):															
January	0	0	0	2	1	0	3	0	0	0	41	9	0	50	.02
February	0	0	2	2	7	1	12	0	0	673	50	9,385	27	10,135	4.10
March	3	3	2	19	12	19	58	61	1,501	294	11,599	6,668	7,186	27,309	11.05
April	6	2	2	28	24	11	73	2,675	32	1,199	26,975	38,443	5,706	75,030	30.36
May	8	1	2	17	14	11	53	2,355	26	988	21,628	12,434	2,960	40,391	16.34
June	7	2	2	16	9	7	43	13,546	71	51	23,149	670	43,817	81,304	32.90
July	0	0	0	6	1	3	10	0	0	0	6,018	36	6,632	12,686	5.13
August	1	0	0	1	(2)		2	42	0	0	170			212	0.09
September	0	0					0	0	0					0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0				0	0	0	0				0	0	0
December	0		0	0	1	0	1	0		0	0	8	0	8	<.01
Total	25	8	10	91	69	52	255	18,679	1,630	3,205	89,630	67,653	66,328	247,125	99.99
Upper central Baja California (lines 110–120):															
January	2	4	1	10	7	2	26	1,026	992	136	21,647	17,536	2,592	43,929	4.92
February	3	5	7	20	10	9	54	52,336	5,911	37,387	13,253	8,738	6,282	123,907	13.87
March	8	10	17	25	9	13	82	87,204	24,450	13,311	23,879	6,497	8,515	163,856	18.34
April	10	11	14	26	14	4	79	22,804	14,772	15,035	13,287	1,569	2,335	69,802	7.81
May	9	14	10	25	5	5	68	19,491	15,416	10,173	13,690	7,822	10,321	76,913	8.61
June	3	13	10	18	4	4	52	393	8,863	3,558	3,722	6,804	186	23,526	2.63
July	2	5	2	4	4	3	20	26,396	2,056	29,047	8,257	4,493	64,162	134,411	15.04
August	3	7	4	3	(2)	6	23	6,916	5,631	148,984	7,252		22,520	191,303	21.41
September	1	4	11			2	18	306	7,165	7,728			6,520	21,719	2.43
October	3	0	1	0	5		9	30,736	0	124	0	2,212		33,072	3.70
November	2	1					3	6,932	12					6,944	.78
December	3		4	1	2		10	1,933		1,682	232	377		4,224	.47
Total	49	74	81	132	60	48	444	256,473	85,268	267,165	105,219	56,048	123,433	893,606	100.01
Lower central Baja California (lines 123–137):															
January	3	3	0	3	2	0	11	10,410	1,450	0	3,855	2,744	0	18,459	2.68
February	2	4	4	4	0	4	18	17,262	1,138	3,006	37,190	0	7,179	65,775	9.55
March	5	13	9	4	1	3	35	177,801	10,003	779	8,245	32	2,054	198,914	28.87
April	4	9	3	5	0	3	24	39,687	7,805	221	495	0	16,379	64,587	9.37
May	3	4	8	2	2	0	19	68,162	3,262	890	2,250	8,230	0	82,794	12.02
June	0	4	3	3	1	2	13	0	10,293	140	1,452	21	10,156	22,062	3.20
July	1	1	3	4	3	0	12	3,814	66	160,052	43,549	6,045	0	213,526	30.99
August	2	2	7	1	(2)	1	13	2,705	8,819	2,683	13		1,063	15,283	2.22
September	1	2				0	3	47	3,024				0	3,071	.45
October	0	2	2	0	1		5	0	536	1,350	0	62		1,948	.28
November	0	1					1	0	8					8	<.01
December	1		0	2	3		6	38		0	341	2,267		2,646	.38
Total	22	45	39	28	13	13	160	319,926	46,404	169,121	97,390	19,401	36,831	689,073	100.01
Southern Baja California (lines 140–157):															
January			0	1	4	1	6			0	15,925	1,044	82	17,051	96.37
February		2			1	1	4		83			434	75	592	3.35
March	0				0		0	0				0		0	0
April						0	0						0	0	0
May															
June	2						2	50						50	.28
July															
August					(2)										
September	0						0	0						0	0
October															
November															
December				0			0				0	0		0	0
Total	2	2	0	1	5	2	12	50	83	0	15,925	1,478	157	17,693	100.00

[1] Area 1 omitted. Only two collections containing sardine eggs were obtained in area 1 (to the north of Point Conception): One in June 1951, the other in June 1954.

[2] Norpac.

sardines. Although the separation of regular spawning from the late-season spawning is much sharper in some seasons than others, I am considering eggs spawned between January and June in this area to belong to the regular spawning group, and eggs spawned during July through December to result from another spawning group.

Lower central Baja California area (lines 123–137)

The composite seasonal distribution of sardine spawning in the lower central Baja California area is bimodal with peaks in March and July. In the 6-year period, 1951–56, about two-thirds of the spawning in this area occurred during the main spawning period, and one-third during the late spawning period. Sampling has been less intensive during the latter half of the year, consequently abundance of eggs during these months has been somewhat underestimated.

The lower central Baja California area decreased in importance as a spawning center between 1950 and 1956. In 1950 and 1951, approximately 50 percent of the total sardine spawning occurred in this area, while in 1955 and 1956 less than 15 percent of sardine eggs were taken here.

Southern Baja California area (lines 140–157)

During the 6-year period under consideration, only 13 cruises extended into the area off southern Baja California. Nine cruises were made in January through March, and the remaining four were made during April, June, September, and December. Sardine eggs were taken in 12 hauls, 6 made during January, 4 during February, and 2 during June. Collections in which eggs were common were obtained only in January.

WATER TEMPERATURE AT TIME OF SPAWNING

There have been no direct observations on sardine spawning, consequently water temperatures at time of spawning have been inferred from temperature observations taken at stations where sardine eggs were obtained.

Studies on vertical distribution of sardine eggs have shown that the eggs are limited in their distribution to the upper mixed layer and the upper portion of the thermocline (Silliman 1943; Ahlstrom 1959). The depth of the upper mixed layer varies from station to station and also at a given station on different occupancies. Sardine eggs have been found to be variously distributed within the mixed layer. In some situations they have been concentrated near the surface or within the upper 10 to 20 meters of depth, at other places they have had a fairly wide distribution within the upper mixed layer or they have been distributed only in the lower portion of the layer.

Although no one level can be representative of the depth distribution of sardine eggs under all conditions, yet on the average the largest concentrations of eggs have been obtained between the surface and about 20 meters. The temperature at a depth of 10 meters has been used in the following analysis. The temperature at this level is much less influenced by diurnal changes than the surface temperature. It is much simpler to obtain than an average temperature for the upper mixed layer, although in many situations it would be identical with such an average and seldom would differ from it by as much as 0.5° C.

In the following analysis, the spawning season has been divided into two parts: main spawning period, extending from January through July in the northern center, January through June in the southern center, and late-season spawning, occurring during July through December in the southern center. Temperature observations are available for 913 collections of sardine eggs made during the major spawning period in 1951 through 1956, and for 121 collections made during the late spawning period.

The frequency of occurrence of sardine eggs at different temperatures is given in table 11 and illustrated in figure 10. Observations from the several geographical areas are summarized separately. Temperature observations are grouped by 0.5° C. intervals.

The temperature range over which sardine eggs were obtained during the major spawning period was from 11.0° to 21.2° C. Approximately 93 percent of the occurrences were at temperatures between 13.0° and 17.9° C., and more than 50 percent of the occurrences were within a 1½° C. range (14.5–15.99° C.). The mean, median, and modal temperatures for the spawning range as a whole fall in the same interval, 15.0–15.49° C. The majority of occurrences at temperatures below 13° C. were in the adjacent 0.5° interval. So few sardine eggs have been taken at temperatures be-

TABLE 11.—*Relation between water temperature and occurrence of sardine eggs, 1951–56*

Temperature at 10 meters (° C.)	Occurrences of sardine eggs during—								
	Main spawning period on lines—						Late-season spawning on lines—		
	80–93	97–107	110–120	123–137	140–157	Total	110–120	123–137	Total
11.0–11.49	1	2				3	1		1
11.5–11.99	2	2				4			
12.0–12.49	5	2	3	2		12			
12.5–12.99	6	6	5	4		21	1		1
13.0–13.49	13	8	5	3		29			
13.5–13.99	22	12	8	5		47	2		2
14.0–14.49	37	31	27	10		105		3	3
14.5–14.99	34	53	58	15		160			
15.0–15.49	17	56	79	17		169	2	2	4
15.5–15.99	6	31	84	20		141	2	3	5
16.0–16.49	10	25	55	8		98	5	4	9
16.5–16.99	8	15	20	8	1	52	5	1	6
17.0–17.49	4	6	12	5	2	29	10	3	13
17.5–17.99	4		2	12	1	19	7	6	13
18.0–18.49	2			3	2	7	6	1	7
18.5–18.99		2		1	1	4	11	4	15
19.0–19.49	1			3		4	8		8
19.5–19.99				1	3	4	12	1	13
20.0–20.49	1	1			1	3	4	2	6
20.5–20.99					1	1	2	2	4
21.0–21.49		1				1	2	1	3
21.5–21.99							1	1	2
22.0–22.49								1	1
23.0–23.49								1	1
23.5–23.99								3	3
27.0–27.49								1	1
Total	173	253	358	117	12	913	81	40	121
Average	14.7	15.1	15.4	15.7	18.7	15.2	18.1	18.0	18.1

low 13° C. that this temperature can be considered a threshhold for Pacific sardine spawning.

During the late spawning period (July–December), sardine eggs were obtained at temperatures between 11.3° and 27.4° C. The average temperature for the 6-year period was 18.1° C. Thus, late-season spawning occurred, on the average, at temperatures which were 2.9° C. higher than during the major spawning period. Less than 3 percent of the occurrences during the major spawning period were at temperatures above 18.0° C., while more than 50 percent of the occurrences during the late spawning period were at temperatures of 18° C. or above.

This marked difference between the average temperature at spawning of the major spawning group of sardines and of the late-season spawning fish has raised the question of whether the late-season spawners may not constitute a separate subpopulation. The subpopulation problem in the Pacific sardine is discussed by Marr (1957). Although the question has been posed from a consideration of time and temperature differences at spawning, the problem will have to be solved by other techniques such as genetic studies of spawning fish of the two groups, growth studies, and a suitable tagging program.

If the late-season spawners off central Baja California do not constitute a separate subpopulation, then one of two explanations must apply: either spawning throughout the year off central Baja California is carried on by the same group of fish, or the late-season spawning is carried on principally by young fish spawning for the first time, probably as 1½-year-old fish. The latter explanation is an appealing one, for if true, it would mean that the late-season spawning could be used to assess the strength of each year class when approximately 1½ years of age.

It is important to know whether the late-season spawners do constitute a separate subpopulation or not. If they are a separate subpopulation with different environmental requirements than the main group of sardines, they may be largely unavailable to the California commercial fishery. Because of this possibility, estimates of egg abundance from late-season spawners have been separated from those of the main spawning group in table 12.

The fluctuation in abundance of eggs is considerably greater during the late-season than during the main spawning period. Sampling during July–December off central Baja California was about equally intensive in 1952 and 1953, yet the estimate of abundance of 352×10^{12} eggs for 1953 was nearly 12 times as large as the estimate of

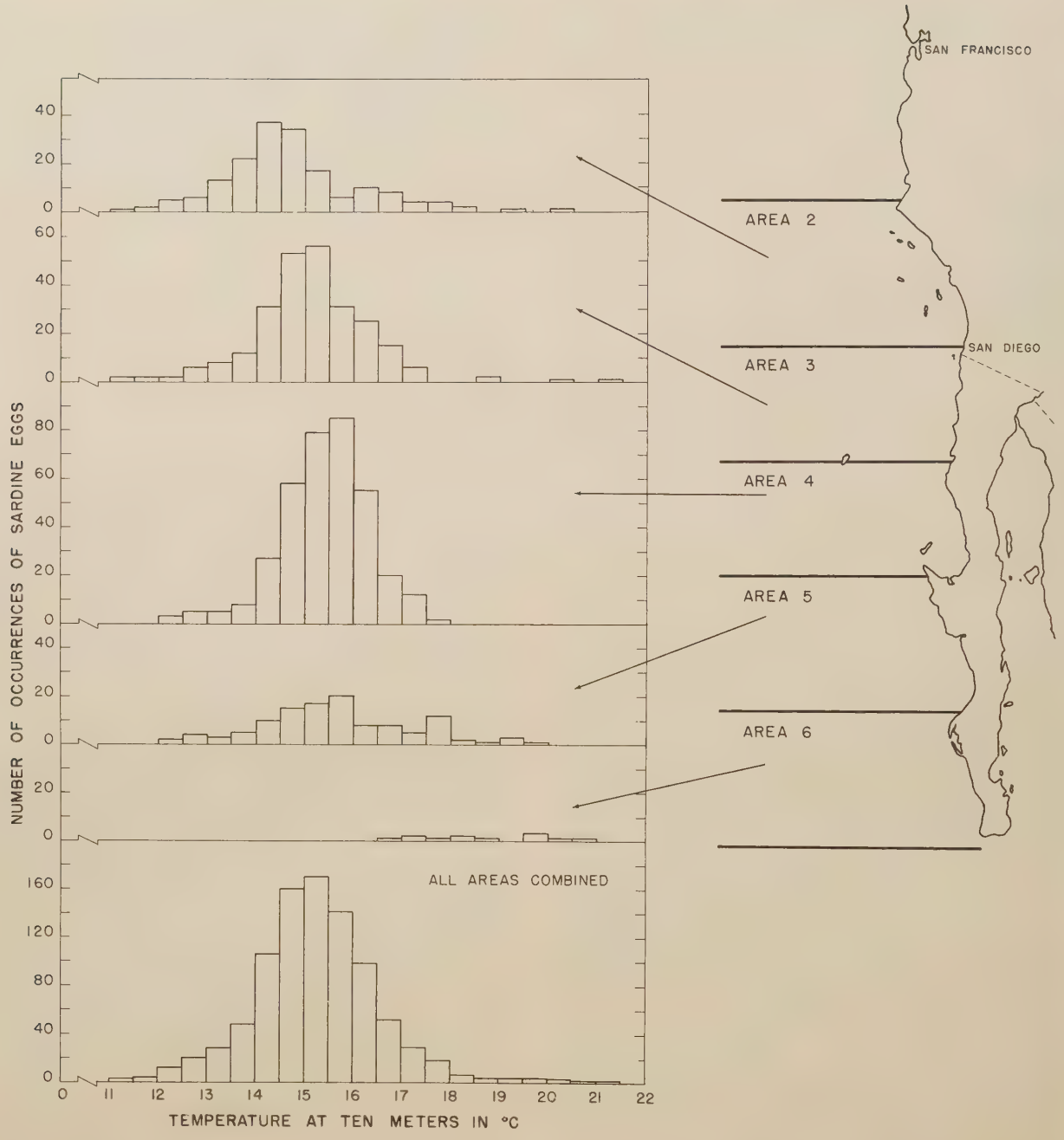

FIGURE 10.—Temperature distribution of sardine eggs during the complete spawning period off southern California and northern Baja California (areas 2 and 3) and during the main spawning period (January–June) off central Baja California (areas 4 and 5) and southern Baja California (area 6).

27×10^{12} eggs for 1952. The lowest estimate of the group, that of 15×10^{12} eggs for 1955, is an underestimate, since collections within the late-season spawning areas were not made during August and September 1955.

Average temperatures at which sardine eggs were obtained in different parts of the spawning range are summarized for the major spawning period by season and area in table 13. The average temperature increased from north to south. For the 6-year period, 1951–56, the amount of the increase going southward from one area to the

TABLE 12.—*Relative contribution to sardine egg estimates of eggs collected during the main spawning period and of eggs collected during late-season spawning, 1951–56*

Area	1951		1952		1953		1954		1955		1956	
	Estimated abundance	Percent of total	Estimated abundance	Percent of total	Estimated abundance	Percent of total	Estimated abundance	Percent of total	Estimated abundance	Percent of total	Estimated abundance	Percent of total
Main spawning period:												
North of Point Conception (lines 60–77)	0	0	0	0	0	0	38	0.01	0	0	0	0
Southern California (lines 80–93)	15,720	2.57	2,663	1.96	675	0.15	47,156	13.27	18,062	11.11	29,250	11.43
Northern Baja California (lines 97–107)	18,679	3.06	1,630	1.20	3,205	.73	89,630	25.22	67,653	41.60	66,328	25.91
Upper central Baja California, Jan.–June (lines 110–120)	183,254	30.00	70,404	51.75	79,600	18.08	89,478	25.18	48,966	30.11	30,231	11.81
Lower central Baja California, Jan.–June (lines 123–137)	313,322	51.29	33,951	24.96	5,036	1.14	53,487	15.05	11,027	6.78	35,768	13.97
Southern Baja California, Jan.–June (lines 140 & below)	50	0	83	0.06	0	0	15,925	4.48	1,478	.91	157	.06
Total	531,025	86.92	108,731	79.93	88,516	20.10	295,714	83.21	147,186	90.51	161,734	63.18
Late season spawning (July–December):												
Upper central Baja California	73,219	11.99	14,864	10.93	187,565	42.61	15,741	4.43	7,082	4.35	93,202	36.41
Lower central Baja California	6,566	1.07	12,453	9.15	164.085	37.30	43,903	12.35	8,374	5.15	1,063	.42
Total	79,785	13.06	27,317	20.08	351,650	79.91	59,644	16.78	15,456	9.50	94,265	36.83

TABLE 13.—*Temperature range and means for stations where sardine eggs were taken, by season and area, for main spawning period*

[Temperature (° C.) at 10 m.]

	1951	1952	1953	1954	1955	1956	All years
Southern California (lines 80–93):							
Number of observations	22	19	10	55	39	28	173
Temperature range	11.8–18.2	12.0–18.2	11.3–16.9	12.8–20.4	12.8–17.9	12.4–17.9	11.3–20.4
Mean temperature	14.8	14.5	13.7	14.9	14.7	14.7	14.7
Northern Baja California (lines 97–107):							
Number of observations	25	6	10	90	70	52	253
Temperature range	11.4–16.9	13.0–15.9	12.6–16.9	11.5–21.2	13.0–17.4	11.2–16.9	11.2–21.2
Mean temperature	15.0	14.6	14.8	15.6	15.1	14.5	15.1
Upper central Baja California (lines 110–120):							
Number of observations	35	57	59	123	48	36	358
Temperature range	12.7–16.5	12.5–17.4	12.7–16.5	12.1–17.9	13.0–16.5	12.2–16.5	12.1–17.9
Mean temperature	15.3	15.9	15.1	15.7	15.2	14.6	15.4
Lower central Baja California (lines 123–137):							
Number of observations	17	34	27	21	6	12	117
Temperature range	13.5–17.9	12.3–19.4	12.8–17.9	12.9–19.9	14.0–15.9	12.4–17.9	12.3–19.9
Mean temperature	16.0	15.8	15.3	16.5	15.1	14.7	15.7
Summation (lines 80–137):							
Number of observations	99	116	106	289	163	128	901
Temperature range	11.4–18.2	12.0–19.4	11.3–17.9	11.5–21.2	12.8–17.9	11.2–17.9	11.2–21.2
Mean temperature	15.2	15.6	15.1	15.6	15.0	14.6	15.2
Southern Baja California (lines 140–157):							
Number of observations	2	1	1	1	5	2	12
Temperature range	17.2–18.1	19.9	20.2	19.7	16.9–20.6	18.2–19.6	16.9–20.6
Mean temperature	17.6	19.9	20.2	19.7	18.3	18.9	18.7

next was roughly uniform at approximately 0.3° C. between each of the four principal areas, but jumped to 3.0° C. from lower central Baja California to southern Baja California.

The average temperature at spawning off southern California during the 6-year period was 14.7° C. In only one year, 1953, did the mean temperature depart from this average by more than 0.2° C. The average temperature at spawning off northern Baja California during 1951–56 was 15.1° C.; the range in average temperature values for the individual years was from 14.5° to 15.6° C. The average temperature at spawning in the northern spawning center, which comprises the above two geographical areas, was 14.9° C. during these years.

Average temperatures at spawning for individual seasons in the upper central Baja California area ranged from 14.6° to 15.9° C.; the average for the 6-year period was 15.4° C. There was a greater spread in the seasonal averages for lower central Baja California, the lowest, 14.7° C. in 1956, being 1.8° C. below the highest, 16.5° C. in 1954. Although there was a 0.3° C. difference between the 6-year average temperatures in the upper and lower central Baja California areas, it should be noted that the average temperatures were almost identical during 4 seasons, and differed by 0.7° to 0.8° C. during the other 2 seasons.

The average temperature at spawning in the southern spawning center (upper and lower central Baja California areas) during the 6-year period was 15.5° C. Thus, the difference in average temperature at spawning in the two major spawning centers was 0.6° C. during the years 1951–56. However, the difference between individual years was as small as 0.1° or 0.2° C. (1955 and 1956) and as large as 1.3° C. (1952), as can be seen from the following summary:

Major spawning period	Average temperature (° C.) in—		Difference (° C.)
	Northern spawnings center (lines 80–107)	Southern spawning center (lines 110–137)	
1951	14.9	15.6	+0.7
1952	14.5	15.8	+1.3
1953	14.2	15.2	+1.0
1954	15.3	15.8	+0.5
1955	15.0	15.2	+0.2
1956	14.5	14.6	+0.1

It is interesting to note that in 1952 and 1953, when there was limited spawning in the northern center, the difference in temperatures between the two centers during the period of spawning was somewhat greater than in the other years.

Although the lowest average temperature in the northern spawning center occurred in 1953, the lowest average temperature throughout the spawning range occurred in 1956 (14.6° C.). The average temperature in the northern center in 1956 was the same as in 1952 and only 0.3° C. higher than in 1953, yet spawning was widespread in the center in 1956 and limited in both amount and extent in 1952 and 1953.

During the years under consideration, the greater abundance of sardine spawning occurred in areas where the average temperature was between 15.0° and 15.9° C. The only exception to this statement is the 1956 season, when average temperatures throughout the spawning range were below 15° C.

Only a limited number of collections of sardine eggs have been obtained off southern Baja California (lines 140–157). In the 6-year period, 1951–56, 12 hauls contained sardine eggs. The temperature range at these stations was from 16.9° to 20.6° C., the mean temperature was 18.7° C. This value is 3° C. higher than the average temperature in the lower central Baja California area during the same period.

Actually, the average temperatures in the southern Baja California area during January through June were as high as the average temperatures during the late-season spawning period, July through December (table 14). If we postulate that the late-season spawning was carried on by a separate subpopulation and use as a major premise the difference in average temperatures between the major spawning period and the late-season spawning, then, by the same reasoning, we are forced to conclude that the sardine spawners off southern Baja California also constitutes a separate subpopulation. I am merely pointing out this fact for consistency, and hasten to add that we have no definite evidence for or against the existence of a separate subpopulation in this area. There is a possibility that the sardines from southern Baja California are more closely allied to sardines in the Gulf of California than to those off central Baja California.

TABLE 14.—*Temperature ranges and means for stations where sardine eggs were taken, summarized by years and area, for late-season spawning*

[Temperature (° C.) at 10 m.]

Year	Lines 110–120			Lines 123–137		
	Number of observations	Temperature range	Mean temperature	Number of observations	Temperature range	Mean temperature
1951	14	17.5–20.9	19.5	5	16.5–23.9	20.4
1952	16	11.3–21.4	17.3	8	15.5–23.4	19.1
1953	22	15.0–21.9	18.2	12	14.0–23.9	18.9
1954	8	16.5–20.4	18.6	7	16.0–20.9	18.1
1955	11	13.5–17.9	16.5	7	14.0–16.5	15.3
1956	10	16.5–20.4	18.6	1	27.0	27.0
Total	81	11.3–21.9	18.1	40	14.0–27.0	18.0

A difficulty in comparing the average temperatures of late-season spawning in different years arises from the paucity of samples in some years. The survey in 1955, for example, was limited to October and December; hence the average temperatures for this year are not strictly comparable with any other year. This is unfortunate, for the limited temperature observations available were markedly lower than during any other season.

RELATION OF EGG ABUNDANCE TO TEMPERATURE

In order to determine whether large concentrations of sardine eggs were taken at temperatures different from those determined for sardine eggs irrespective of abundance, average temperatures

were obtained for those hauls containing 101 or more eggs. The results are summarized by area for the 1951–56 period:

Area	Station lines	All hauls of sardine eggs		Hauls of 101 or more sardine eggs	
		Number of hauls	Average temperature (° C.)	Number of hauls	Average temperature (° C.)
Southern California	80–93	173	14.7	51	14.9
Northern Baja California	97–107	253	15.1	82	15.2
Upper central Baja California	110–120	358	15.4	143	15.3
Lower central Baja California	123–137	117	15.7	60	15.6

The average temperature at which hauls containing larger concentrations of sardine eggs were made was very similar to the average for all hauls. In only one instance was the temperature difference between the two groups of hauls as large as 0.2° C.

In an analysis of the relation of jack mackerel larvae to temperature, Ahlstrom and Ball (1954), using temperatures at 20-meter depths, found that hauls containing a large number of larvae (101 larvae or more per haul) were associated with a more limited temperature range, 12.5–17.0° C., and lower mean temperature, 14.75° C., than hauls containing only 1 to 10 larvae. The temperature range for the latter group was from 10.0° to 19.0° C., and the mean temperature was 15.45° C.

TEMPERATURE CONDITIONS IN 1940 AND 1941

Sardine spawning surveys made in 1940 and 1941 covered an area off southern California that presently would be included in the southern California area (Sette and Ahlstrom, 1948; Ahlstrom 1948). The ranges and means of water temperatures at stations where sardine eggs were taken during these years are summarized, by cruise, in table 15. Temperature observations for 1940 were taken from Sverdrup et al. (1944); for 1941 from Sverdrup et al. (1947). The average temperature for the 1940 season was 15.1° C. and for the 1941 season 16.1° C. The average temperature at which sardine eggs were taken in 1940 was 0.2° C. higher than that off southern California during any year between 1951 and 1956, and the average temperature in 1941 was 1.2° C. higher. The average temperature off southern California in 1941 was higher than the average temperature at which sardine eggs were obtained off lower central Baja California (lines 123–137) during 5 of 6 years between 1951 and 1956. We have no information on either sardine spawning or water temperatures off central Baja California in 1941, so cannot compare the temperatures in that region in 1941 with those obtained off southern California.

TABLE 15.—*Temperature range and mean for stations where sardine eggs were taken, summarized by cruises, 1940 and 1941*

[Temperature (° C.) at 10 m.]

Cruise number	Date	Number of occurrences	Temperature range (° C.)	Mean temperature (° C.)
1940				
10	III: 5–14	37	13.65–16.09	15.2
11	III: 20–28	31	13.83–15.86	15.0
12	IV: 4–14	32	13.28–16.01	14.9
13	IV: 22–V: 3	31	12.68–16.62	14.8
14	V: 10–21	32	12.59–18.94	15.3
15	V: 27–VI: 7	18	13.26–17.32	15.8
Season		181	12.59–18.94	15.1
1941				
17	III: 21–30	41	14.98–17.86	16.2
19	IV: 14–25	35	14.10–16.90	15.4
21	V: 8–17	27	14.57–18.79	16.4
23	VI: 2–12	18	13.80–18.13	15.7
25	VI: 25–VII: 3	11	14.39–19.14	16.5
27	VII: 21–28	5	13.47–20.11	18.2
Season		137	13.47–20.11	16.1

Temperatures during the 1941 spawning season point up the fact that there can be greater temperature differences between years in a geographical area, such as the southern California area, than are normally encountered in different parts of the spawning range during a spawning season.

SUMMARY

The distribution and abundance of sardine eggs are discussed and illustrated for the years 1952 through 1956.

Distribution of spawning in 1952 and 1953 was mostly confined to the southern spawning center, off central Baja California.

In 1954, a marked change occurred in the distribution of sardine eggs: heavy and widespread spawning occurred off southern California and adjacent northern Baja California (northern spawning center), as well as in the area off central Baja California. There was a ten-fold increase in the extent of sardine spawning in the northern center

in 1954 as compared with 1953, and a 35-fold increase in the abundance of sardine eggs.

The extent of sardine spawning in the northern spawning center was greater than in the southern center in both 1955 and 1956. Compared with 1954, however, there was a progressive decrease in the areal distribution of spawning in these years.

Estimates of numbers of sardine eggs spawned during 1952–56 were as follows: for 1952, 136×10^{12}; for 1953, 436×10^{12}; for 1954, 355×10^{12}; for 1955, 163×10^{12}; for 1956, 256×10^{12}. The estimate for 1955 is too low by perhaps 15 percent because of lack of sampling in August and September 1955, during the Norpac expedition.

The occurrences of sardine eggs in the northern spawning center were mostly limited to the months of February through July. Off southern California, heavy spawning took place in May and June, while off northern Baja California heavy spawning commenced in April and continued through June.

Sardine eggs were obtained throughout the year in the southern spawning center. To the north of Point San Eugenio (upper central Baja California area), a composite seasonal distribution showed peaks in March and August, while to the south of Point San Eugenio (lower central Baja California) the peaks occurred in March and July.

During the major spawning period, sardine eggs have been collected at temperatures between 11.0° and 21.2° C., with more than half of the observations occurring within a 1½° C. range (14.5°–15.99° C.). During the late spawning period (July–December), sardine eggs have been collected at temperatures between 11.3° and 27.4° C. The mean temperature of 18.1° C. in the late spawning period was 2.9° C. higher than the mean temperature of 15.2° C. in the major spawning period.

The average temperature at spawning off southern California during the 6-year period was 14.7° C.; off northern Baja California, 15.1° C.; off upper central Baja California, 15.4° C. (major spawning period, January–June); and off lower central Baja California, 15.7° C. (major spawning period, January–June). Thus, the average temperature at which sardine spawning took place increased from north to south in a fairly uniform fashion.

The difference in temperatures between the two principal spawning centers was found to be greater in 1952 and 1953 than in the other years.

A limited number of samples of sardine eggs off southern Baja California were collected at an average temperature that was nearly 3° C. higher than the average temperature in the southern spawning center during the same period of the year.

When sardine eggs were grouped according to abundance, no difference was found in the temperatures at which they occurred.

The average temperature at which sardine eggs were obtained off southern California in 1940 was slightly higher than in any year between 1951 and 1956, but the average temperature in 1941 was more than 1° C. higher.

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